CHAPTER 18

FOUNDATIONS AND RETAINING WALLS

(This Chapter is unique to Massachusetts)

780 CMR 1801.0 GENERAL

1801.1 Scope: The provisions of 780 CMR 18 shall control the foundation design and construction of all buildings and structures hereafter erected to insure adequate strength of all parts thereof for the safe support of all superimposed *live* and *special loads*, in addition to their own *dead load*, without exceeding the allowable stresses or design capabilities.

780 CMR 1802.0 FOUNDATION INVESTIGATIONS

1802.1 Where required: Borings, test pits or other soil investigations shall be required for all structures except the following, unless specifically required by the code official:

1. one- and two-family dwellings and their accessory buildings;
2. structures less than 35,000 cubic feet in gross volume; or
3. structures used for agricultural purposes.

The borings, test pits or other soil investigations shall be adequate in number and depth and so located to accurately define the nature of the subsurface materials necessary for the support of the structure. When it is proposed to support the structure directly on bedrock, the code official shall require core borings to be made into the rock; or shall require other satisfactory evidence to prove that the structure shall be adequately founded on bedrock.

1802.1.1 Seismic investigation: Where the foundation investigation indicates subsoils of Material Classes 8 or 9, as defined in Table 1804.3, a soil investigation report which evaluates the potential hazards due to liquefaction and slope instability during an earthquake shall be submitted to the code official. The liquefaction evaluation shall be performed in accordance with 780 CMR 1805.3

1802.2 Soil samples and boring reports: Samples of the strata penetrated in test borings or test pits, representing the natural disposition and conditions at the site, shall be available for examination by the code official. Wash or bucket samples shall not be accepted. Duplicate copies of the results obtained from all borings and of all test results or other pertinent soil data shall be filed with the code official.

780 CMR 1803.0 SOIL BEARING TESTS

1803.1 General: Whenever the allowable bearing pressure on bearing materials is in doubt, the code official may require soil bearing tests. The tests shall be performed under the direction of a *registered design professional*. A complete record of the test results together with a soil profile shall be filed by the *registered design professional* who shall have a representative on the site during all boring and test operations.

1803.2 Loaded areas: The loaded area shall be approximately four square feet for all bearing materials; except that when the footing overlies wet clay or other soft materials, the test load shall be applied to an area of not less than ten square feet. Bearing tests shall be applied at the elevations of the proposed bearing surfaces of the structure; except that the load may be applied directly on the surface of compacted granular material. The excavation within three feet (1 m) surrounding an area to be tested shall be made not deeper than one foot (0.3 m) above the plane of application of the test. The test plate shall be placed with uniform bearing.

1803.3 Loading procedure: The application of the test load shall be in steps equal to not more than ½ the contemplated design bearing pressure, to at least twice the contemplated design bearing pressure. The unloading shall be at least two steps, to the design pressure and then to zero load. The contemplated design pressure and twice the contemplated design pressure shall be maintained constant for at least 24 hours and until the movement does not exceed two hundredths of an inch (0.5 mm) during a 24-hour period. The load for all other load and unload steps including the zero load at the end of the test shall be maintained constant for a period of not less than four hours. Sufficient readings for each load step shall be made to define properly the time-deflection curve.

1803.4 Accuracy of loading: Test loads applied by mechanical devices shall be automatically controlled so as to insure not more than a 5% variation in applied load. Such devices shall be calibrated prior to the test.

1803.5 Test acceptance: The proposed design load shall be allowed provided that the requirements of 780 CMR 1805.5 are fulfilled and the settlements under the design bearing pressure and twice the design bearing pressure do not exceed _ of an inch (10 mm) and one inch (25 mm), respectively.

780 CMR 1804.0 LOAD BEARING VALUE OF SOILS

1804.1 Soils report: All applications for permits for the construction of new buildings or structures, and for the *alteration* of permanent structures which require changes in foundation loads and distribution, shall be accompanied by a report describing the soil in the ultimate loadbearing strata, including sufficient data to establish its character, nature and loadbearing capacity. The report shall be prepared by a *registered design professional*.

1804.2 Satisfactory foundation materials: Satisfactory bearing strata to provide structural support shall be considered to include the following: natural strata of rock, gravel, sand, inorganic silt, inorganic clay, or combination of these materials provided that they do not overlie an appreciable amount of peat, organic silt, soft clay or other objectionable materials. Compacted fills, when designed and monitored by a *registered design professional*, may be accepted by the code official. Other conditions of unsatisfactory bearing materials which are improved in accordance with the recommendations of, and monitored by, a *registered design professional* may be accepted by the code official.

1804.2.1 Loading interaction: Wherever bearing strata are subject to interaction from other loadings or strata reactions, such conditions shall be incorporated in the evaluation of the design bearing capacity of the support strata.

1804.2.2 Protection of bearing strata: Bearing strata which may be adversely affected by conditions within the structure, such as evaporation and shrinkage due to excess heat or cold, shall be adequately protected.

1804.3 Presumptive load bearing values: The maximum allowable pressure on supporting soils under spread footings at or near the surface shall not exceed the values specified in Table 1804.3 or the maximum allowable pressure shall be determined by load tests conducted in the field or as otherwise provided herein. Presumptive loadbearing values shall apply to all materials with similar physical characteristics. Surface values shall be adjusted for deep footings and for weaker loadbearing strata below piles, as provided for in 780 CMR 1817.8. Higher allowable bearing pressures may be approved by the code official when substantiated by the results of investigations, analyses or testing prepared by a *registered design professional*.

1804.3.1 Classification of bearing materials: The terms used in 780 CMR 1804 shall be interpreted in accordance with generally accepted engineering nomenclature. Refer to commentary in Appendix D for guidelines regarding soil and rock classification and description.

1804.3.2 Prepared fill: Materials from Classes 6 through 8, Table 1804.3, or dense graded crushed stone or slag, which contain no plastic fines, shall have a maximum allowable bearing pressure of up to five tons per square foot when compacted to 95% or greater of the maximum dry density as determined by ASTM D1557 listed in ***Appendix A***. For compacted fills which do not meet the above criteria or materials which cannot be tested as above, a *registered design professional* shall be engaged to provide recommendations for compaction and maximum allowable design bearing pressures.

1804.3.3 Field Control: The code official will require that a *registered design professional* or his representative be on the project at all times while fill is being placed and compacted. The representative shall make an accurate record of the types of materials used, including grain-size curves, thickness of lifts, densities, percent compaction, type of compacting equipment and number of coverages, the use of water and other pertinent data.

Table 1804.3
ALLOWABLE BEARING PRESSURES FOR
FOUNDATION MATERIALS

Material Class	Description	Notes	Consistency in Place[1]	Allowable Net Bearing Pressure (tons/ft^2)
1a	Massive bedrock: Granite, diorite gabbro, basalt, gneiss	3	Hard, sound rock, minor jointing	100
1b	Quartzite, well cemented conglomerate	3	Hard, sound rock moderate jointing	60
2	Foliated bedrock: slate, schist	3	Medium hard rock, minor jointing	40
3	Sedimentary bedrock: cementation shale, siltstone, sandstone, limestone, dolomite, conglomerate	3, 4	Soft rock, moderate jointing	20
4	Weakly cemented sedimentary bedrock: compaction shale or other similar rock in sound condition	3	Very soft rock	10
5	Weathered bedrock: any of the above except shale.	3, 5	Very soft rock, weathered and/or major jointing and fracturing	8
6	Slightly cemented sand and/or gravel, glacial till (basal or lodgement), hardpan	7,8	Very dense	10
7	Gravel, widely graded sand and gravel; and granular ablation till	6, 7, 8	Very dense Dense Medium dense Loose Very loose	8 6 4 2 Note 11
8	Sands and non-plastic silty sands with little or no gravel (except for Class 9 materials)	6, 7, 8, 9	Dense Medium dense Loose Very loose	4 3 2 Note 11
9	Fine sand, silty fine sand, and non-plastic inorganic silt	6, 7, 9	Dense Medium dense Loose Very loose	3 2 1 Note 11
10	Inorganic sandy or silty clay, clayey sand, clayey silt, clay, or varved clay; low to high plasticity	5, 6, 10	Hard Stiff Medium Soft	4 2 1 Note 11
11	Organic soils: peat, organic silt, organic clay	11		Note 11

Notes for Table 1804.3:

1. Refer to commentary in Appendix D regarding typical index test values that may be helpful as guides for evaluation of consistency in place.
2. Refer to 780 CMR 1807.0 for determination of design loads and for special cases.
3. The allowable bearing pressures may be increased by an amount equal to 10% for each foot of depth below the surface of sound rock; however, the increase shall not exceed two times the value given in the table.
4. For limestone and dolomite, the bearing pressures given are acceptable only if an exploration program performed under the direction of a *registered design professional* demonstrates that there are no cavities within the zone of influence of the foundations. If cavities exist, a special study of the foundation conditions is required.
5. Weathered shale and/or weathered compaction shale shall be included in Material Class 10. Other highly weathered rocks and/or residual soils shall be treated as soil under the appropriate description in Material Classes 6 to 10. Where the transition between residual soil and bedrock is gradual, a *registered design professional* shall make a judgment as to the appropriate bearing pressure.
6. Settlement analyses in accordance with 780 CMR 1805.5 should be performed if the ability of a given structure to tolerate settlements is in question, particularly for, but not limited to, soft or very soft clays and silts and loose granular materials.
7. Allowable bearing pressures may be increased by an amount equal to 5% for each foot of depth of the bearing area below the minimum required in 780 CMR 1806.0; however, the bearing pressure shall not exceed two times the value given in the table. For foundation bearing areas having a least

lateral dimension smaller than three feet, the allowable bearing pressure shall be _ of the tabulated value times the least dimension in feet.

8. Refer to 780 CMR1804.3 when these materials are used as compacted fills.
9. These materials are subject to the provisions in 780 CMR 1805.3 (Liquefaction).
10 Alternatively, the allowable bearing pressure may be taken as 1.5 times the peak unconfined compressive strength of undisturbed samples for square and round footings or 1.25 times that strength for footings with length to width ratio of 4 or greater. For intermediate cases, interpolation may be used.
11. A *registered design professional* shall be engaged to provide recommendations for these special cases. Direct bearing on organic soils is not permitted. Organic soils are allowed under foundations for those cases defined in 780 CMR 1804.4.2, Preloaded materials.

1804.4 Lightweight structures: One-story structures without masonry walls and not exceeding 800 square feet in area may be founded on a layer of satisfactory bearing material not less than three feet (1 m) thick, which is underlain by highly compressible material, provided that the stresses induced in the unsatisfactory material by the *live* and *dead loads* of the structure, and the weight of any new fill within or adjacent to the building area, will not exceed 250 pounds per square foot (250 psf).

1804.4.1 Bearing capacity for lightweight structures: Lightweight structures and accessory structures, such as garages and sheds, may be founded on normally unacceptable bearing strata, providing such material is determined by a *registered design professional* as being satisfactory for the intended use.

1804.4.2 Preloaded materials: The code official may allow the use of certain otherwise unsatisfactory natural soils and uncompacted fills for support of one-story structures after these materials have been preloaded to effective stresses not less than 150% of the effective stresses which will be induced by the live and *dead loads* of the structure.

1804.4.3 Load test: The code official may require the loading and unloading of a sufficiently large area, conducted under the direction of a *registered design professional* approved by the code official, who shall submit a report containing a program which will allow sufficient time for adequate consolidation of the material based on an analysis of the preloaded material and of the probable settlements of the structure.

780 CMR 1805.0 ALLOWABLE FOUNDATION LOADS

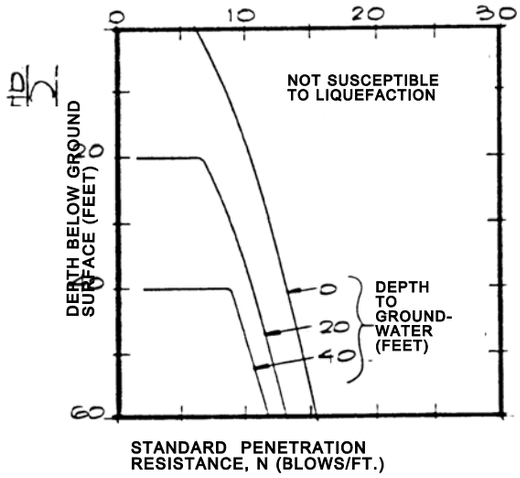
1805.1 General: The maximum allowable pressures on foundation materials shall be in accordance with 780 CMR 1804.0 and as modified herein.

1805.2 Soil Capacity: For the load combinations, including seismic as specified in 780 CMR 1616.0, the soil loadbearing strength shall be sufficient to resist loads at acceptable strain, considering both the duration of the loading and the dynamic properties of the soil. For foundations supported on or in Material Classes 1 through 6, as defined in Table 1804.3, or medium dense to very dense soils of Material Classes 7 through 9, or stiff to hard soil of Materials Class 10, the allowable bearing pressure or pile or pier capacity may be increased by up to 33% for load combinations that include wind or seismic loading.

1805.3 Liquefaction:

1. The earthquake liquefaction potential of saturated clean medium to fine sands shall be evaluated on the basis of Figure 1805.3 for cases where lateral sliding cannot occur.

Figure 1805.3
LIQUEFACTION SUSCEPTABILITY



If the standard resistances, N, in all strata of medium to fine sand lie above the applicable curve in Figure 1805.3 the sands at the site shall not be considered subject to liquefaction. Liquefaction below a depth of 60 feet (18 m) from final grade need not be considered for level ground. For pressure-injected footings, the ten-foot (3-m) thickness of soil immediately below the bottom of the driven shaft shall not be considered subject to liquefaction.

2. Compacted granular fills shall not be considered subject to liquefaction provided they are systematically compacted to at least 93% of

maximum dry density as determined in accordance with ASTM Standard Method D1557, listed in ***Appendix A*** or to a relative density of at least 60% in the case of granular soils having less than 10% by weight material passing the No. 200 U.S. Sieve.

3. For sites not meeting the above criteria, studies by a *registered design professional* shall
   - Design of foundations that will not fail either by loss of bearing capacity or excessive settlement if liquefaction occurs.
   - Replacement or densification of liquefaction-susceptible soils such that liquefaction will not occur.

4. For sites underlain by saturated sands where lateral sliding (slope instability) may occur, studies by a *registered design professional* shall be made to establish the safety against sliding during an earthquake with a peak acceleration of 0.12 g and a frequency content similar to that implied by the modal seismic design coefficient set forth in 780 CMR 1612.0

5. For sites underlain by saturated silty sands and inorganic non-plastic silts, studies shall be made by a *registered design professional* to determine the susceptibility to liquefaction of these soils.

1805.4 Vertical pressure: The computed vertical pressure at any level beneath a foundation shall not exceed the allowable bearing pressure for the material at that level. Computation of the vertical pressure in the bearing materials at any depth below a foundation shall be made on the assumption that the load is spread uniformly at an angle of 30° with the vertical; but the area considered as supporting the load shall not extend beyond the intersection of 30° planes of adjacent foundations.

1805.5 Settlement analysis: Whenever a structure is to be supported by medium or soft clay (materials of Class 10) or other materials which may be subject to settlement or consolidation, the settlements of the structure and of neighboring structures due to consolidation shall be given careful consideration, particularly if the subsurface material or the loading is subject to significant variation. The code official may require a settlement analysis to be made by a *registered design professional* when the *live* and *dead loads* of the structure, as specified in this article, minus the weight of the excavated material, induce a maximum stress greater than 300 pounds per square foot at mid-depth of the underlying soft soil layer.

Settlement analysis will be based on a computation of the new increase in stress that will be induced by the structure and realistically appraised *live loads*, after deducting the weight of excavated material under which the soil was fully consolidated. The effects of fill loads within the building area or fill and other loads adjacent to the building shall be included in the settlement analysis. The appraisal of the *live loads* may be based on surveys of actual *live loads* of existing buildings with similar occupancy. The soil compressibility shall be determined by a *registered design professional*.

be made to determine that the structural loads can be safely supported. Such studies might include the following:
   - Investigations to establish that the soils at the site are not subject to liquefaction during the design earthquake as specified in 780 CMR 1612.0.

1805.6 Disturbance of bearing materials: Whenever the bearing materials are disturbed from any cause, for example, by the inward or upward flow of water and/or by construction activities, the extent of the disturbance shall be evaluated by a *registered design professional* and appropriate remedial measures satisfactory to the code official shall be taken.

1805.7 Rock foundations: Where subsurface explorations at the project site indicate variations or doubtful characteristics in the structure of the rock upon which it is proposed to construct foundations, a sufficient number of borings shall be made to a depth of not less than ten feet below the level of the foundations to provide assurance of the soundness of the foundation stratum and its bearing capacity. Refer to Table 1804.3 for allowable bearing pressures and special conditions.

The maximum presumptive loadbearing capacity of Class 1 or Class 2 rock may be increased where the surface is leveled or benched, provided that such increased safe capacity is determined by load tests on an area of not less than one square foot (0.093 m^2) in accordance with the provisions of 780 CMR 1803.0.

780 CMR 1806.0 DEPTH OF FOOTINGS

1806.1 Frost protection: All permanent supports of buildings and structures larger than 100 square feet (9.3 m^2) in area or ten feet (3 m) in height shall extend to a minimum of four feet (1.2 m) below finished grade except when erected upon sound bedrock or when protected from frost, or when the foundation grade is established by a *registered design professional* and as approved by the code official. Spread footings of adequate size shall be provided where necessary to distribute properly the load within the allowable load bearing value of the soil. Footings shall not bear on frozen soils.

1806.2 Isolated footings: Footings on granular soil of Classes 7, 8 and 9 of Table 1804.3 and compacted fill shall be so located that the line drawn between the lower edges of adjoining footings shall not have a steeper slope than 30° (0.52 rad) with the horizontal unless the material supporting the higher footing is braced or retained or otherwise laterally supported in an approved manner or a greater slope has been properly established by a *registered design professional*.

1806.3 Depth of spread foundations: The bottom surface of any footing resting on material of Classes 5 through 10 of Table 1804.3, shall be at least 18 inches (460 mm) below the lowest ground surface or the top surface of a floor slab bearing directly on the soil immediately adjacent to the footing.

780 CMR 1807.0 FOOTING DESIGN

1807.1 Design loads: The loads to be used in computing the pressure upon bearing materials directly underlying foundations shall be the *live* and *dead loads* of the structure, as specified in 780 CMR 1616.0 including the weight of the foundations and of any immediately overlying material, but deducting from the resulting pressure per square foot the total weight of a one-foot-square column of soil, including the water in its voids, which extends from the lowest immediately adjacent surface of the soil to the bottom of the footing, pier or mat. Foundations shall be constructed so as to resist the maximum probable hydrostatic pressures.

1807.2 Vibratory loads: Where machinery operations or other vibrations are transmitted through the foundation, consideration shall be given in the footing design to prevent detrimental disturbances of the soil.

1807.3 Varying unit pressures: Footings shall be so designed that the unit soil pressure under the *dead load* shall be as uniform as possible under all parts of the building structure. When necessary for stability in the structure due to settlement or varying soil conditions, approved variations are permitted in the unit pressure under different footings.

1807.4 Eccentric loads: Eccentricity of loadings in foundations shall be fully investigated, and the maximum pressure on the basis of straight-line distribution shall not exceed the allowable bearing pressures.

1807.5 Protection of footings: Trenching installed parallel to footings shall not extend below the line of a 45° (0.79 rad) angle downward from the loadbearing plane of the footing.

780 CMR 1808.0 TIMBER FOOTINGS AND WOOD FOUNDATIONS

1808.1 Timber footings: Timber footings are permitted for buildings of Type 5 construction and as otherwise approved. Such footings shall be treated in accordance with AWPA C2 or C3 listed in ***Appendix A***. Treated timbers are not required where placed entirely below permanent water level, or where used as capping for wood piles which project above the water level over submerged or marsh lands. The compressive stresses perpendicular to grain in untreated timber footings supported upon piles shall not exceed 70% of the allowable stresses for the species and grade of timber as specified in NFoPA NDS listed in ***Appendix A***.

1808.2 Pole buildings: Pole-type buildings shall be designed and erected in accordance with AWPI *Pole Building Design* listed in ***Appendix A***. The poles shall be treated in accordance with AWPA C2 or C4 listed in ***Appendix A***.

1808.3 Wood foundations: Wood foundation systems shall be designed and installed in accordance with NFoPA TR7 listed in ***Appendix A***. All lumber and plywood shall be treated in accordance with AWPA C22 listed in ***Appendix A*** and shall be identified in accordance with 780 CMR 2311.3.1.

780 CMR 1809.0 STEEL GRILLAGES

1809.1 General: All steel grillage beams shall be separated with approved steel spacers and shall be entirely encased in at least three inches (76 mm) of concrete, and the spaces between the beams shall be completely filled with concrete or cement grout. Where used on yielding soils, steel grillages shall rest on approved concrete beds not less than six inches (152 mm) thick.

780 CMR 1810.0 CONCRETE FOOTINGS

1810.1 Concrete strength: Concrete in footings shall have a specified compressive strength of not less than 2,500 psi (1.76 kg/mm^2) at 28 days.

1810.2 Design: Concrete footings shall comply with 780 CMR 19 and ACI 318 or ACI 318.1 listed in ***Appendix A***.

1810.2.1 Footing seismic ties: Individual spread footings, located on soil profile type S2, S3 or S4, in accordance with 780 CMR 1612.4.2, and supporting buildings assigned to *Seismic Performance Category D,* in

accordance with 780 CMR 1612.2.7, shall be interconnected by ties. All ties shall be capable of resisting, in tension or compression, a force equal to 10% of the larger column *dead plus live load*. Individual tie beams are not required when it is demonstrated that equivalent restraint will be provided by structural members within slabs on grade or reinforced concrete slabs on grade or confinement be competent rock, hard cohesive soils, very dense granular soils or other approved means.

1810.3.2 Reinforced concrete: In reinforced concrete footings, the thickness above the bottom reinforcement shall not be less than six inches (152 mm) for footings on soil. The clear cover on reinforcement where the concrete is cast against the earth shall not be less than three inches (76 mm). Where concrete is exposed to soil after it has been cast, the clear cover shall not be less than 1½ inches (38 mm) for reinforcement of No. 5 bars or _-inch (16 mm) diameter wire or smaller, nor less than two inches (51 mm) for larger reinforcement.

1810.4 Deposition: Concrete footings shall not be placed through water unless otherwise approved. Where placed under or in the presence of water, the concrete shall be deposited by approved means to insure minimum segregation of the mix and negligible turbulence of the water.

1810.5 Protection of concrete: Concrete footings shall be protected from freezing during depositing and for a period of not less than five days thereafter. Water shall not be allowed to flow through the deposited concrete.

1810.6 Forming of concrete: Concrete footings shall not be cast against the earth where, in the opinion of the code official, soil conditions warrant forming. Where forming is required, forming shall be in accordance with Chapter 6 of ACI 318 listed in ***Appendix A***.

780 CMR 1811.0 MASONRY-UNIT FOOTINGS

1811.1 Dimensions: Masonry-unit footings shall be laid in Type M or S mortar complying with 780 CMR 2105.7, and the depth shall not be less than twice the projection beyond the wall, pier or column. The width shall not be less than eight inches (203 mm) wider than the wall supported thereon.

1811.2 Offsets: The maximum offset of each course in brick foundation walls stepped up from the footings shall be 1½ inches (38 mm), if laid in

1810.3 Thickness: The thickness of concrete footings shall comply with 780 CMR 1810.3.1 and 1810.3.2.

1810.3.1 Plain concrete: In plain concrete footings, the edge thickness shall not be less than eight inches (203 mm) for footings on soil; except that for occupancies of Use Group R-3 and buildings less than two stories in *height* of Type 5 construction, the required edge thickness shall be six inches (152 mm) provided that the footing does not extend beyond four inches (102 mm) on either side of the supported wall.

single courses, and three inches (76 mm), if laid in double courses.

780 CMR 1812.0 FOUNDATION WALLS

1812.1 Design: Foundation walls shall be designed to resist frost action and to support safely all vertical and *lateral loads* as provided for in 780 CMR 16. The maximum stresses caused by combined loads shall be within the values specified for the materials used in the construction. Unless properly reinforced, tensile stresses shall not exceed those permitted in plain masonry.

1812.2 Definitions: The following words and terms shall, for the purposes of 780 CMR 1812 and as used elsewhere in 780 CMR, have the meanings shown herein.

Foundation wall: A wall below the floor nearest grade which serves as a support for a wall, pier, column or other structural part of a building.

Retaining wall: A wall designed to resist the lateral displacement of soil or other material.

1812.3 Minimum thickness: The thickness of foundation walls shall not be less than the thickness of the wall supported, and the minimum thickness shall be limited for the various materials of construction as herein specified. Eight-inch foundation walls shall be permitted under brick-veneered frame and under ten-inch cavity walls where the total height of the wall supported, including gables, is not more than 20 feet (6 m).

1812.3.1 Reinforced concrete: Reinforced concrete exterior foundations and exterior and interior *basement* walls which retain or support the lateral pressure of earth or water shall not be less than 7½ inches (191 mm) thick.

1812.3.2 Hollow and solid masonry and plain concrete: The thickness of masonry foundation walls shall not be less than shown in Table 1812.3.2 for the type of foundation used. Where the height of the unbalanced fill (height of finished ground level above the *basement*

floor or inside ground level) exceeds eight feet (2.4 m) or where the equivalent fluid weight of the unbalanced fill exceeds 30 pounds per cubic foot (pcf) (146 kg/m^3) or where the height of the foundation wall between lateral supports exceeds eight feet (2.4 m), the foundation wall thickness shall be determined by structural analysis in accordance with ACI 530/ASCE 5/ TMS 402 or ACI 318.1 listed in ***Appendix A***.

Table 1812.3.2
THICKNESS OF FOUNDATION WALLS

Foundation wall construction	Thickness[b] (inches)	Maximum depth of unbalanced fill[a] (feet)
Masonry of hollow units Ungrouted	8	4
	10	5
	12	6
Masonry of hollow units, reinforced vertically with #4 bars and grout at 24" o.c. Bars located not less than 4½" from pressure side of wall[c,d]	8	7
Masonry of solid units	8	5
	10	6
	12	7
Plain concrete or masonry of hollow or solid units, fully grouted	8	7
	10	8
	12	8

Note a. Maximum depths of unbalanced fill shall be permitted to be increased with the approval of the code official where soil conditions or local experience warrant such increase.

Note b. The actual thickness shall not be more than ½ inch less than the required nominal thickness specified in the table.

Note c. Other bar sizes and spacings shall be permit-ted as determined by structural analysis as required in ACI 530/ASCE 5/TMS 402 listed in ***Appendix A***.

Note d 1 inch = 25.4 mm; 1 foot = 304.8 mm.

1812.3.3 Hollow-unit walls: Foundation walls of approved hollow masonry units shall be provided with not less than four inches (102 mm) of solid masonry at girder supports, or shall be strengthened with buttresses.

1812.3.4 Rubble stone: Foundation walls of rough or random rubble stone shall not be less than 16 inches (406 mm) thick.

1812.3.5 Bonding: All foundation walls shall be bonded as required for superstructure walls in 780 CMR 2110.0.

1812.4 Increased thickness with depth: Where any foundation wall, other than a wall that is designed as a retaining wall, extends more than 12 feet (3.7 m) below the top of the first floor beams, the thickness of the wall shall be increased four inches (102 mm) for each additional 12 feet (3.7 m) or fraction thereof in depth.

1812.5 Corbels on eight-inch walls: Where an eight-inch (203 mm) wall is corbelled, the top corbel shall be a full course of headers at least six inches (152 mm) in length, extending not higher than the bottom of the floor framing. The maximum projection of one unit shall exceed neither ½ of the depth of the unit nor _ of its width at right angles to the face which is offset.

1812.6 Lateral stability: Foundation walls of buildings and structures which serve as retaining walls shall conform to the applicable requirements of 780 CMR 1825.0, and shall be strengthened with buttresses or additional wall thickness to resist lateral soil and hydrostatic pressure where subjected thereto, and to resist seismic loads as required by 780 CMR 1612.4.9.

780 CMR 1813.0 WATERPROOFING AND DAMPPROOFING

1813.1 Where required: Walls or portions thereof that retain earth and enclose interior spaces and floors below grade shall be waterproofed and dampproofed in accordance with 780 CMR 1813.0, with the exception of those spaces containing use groups other than residential and institutional where such omission is not detrimental to the building or occupancy.

1813.1.1 Story above grade: Where a *basement* is considered a *story above grade* and the finished ground level adjacent to the *basement* wall is below the *basement* floor elevation for 25% or more of the perimeter, the floor and walls shall be dampproofed in accordance with 780 CMR 1813.3 and a foundation drain shall be installed in accordance with 780 CMR 1813.5.2. The foundation drain shall be installed around the portion of the perimeter where the *basement* floor is below ground level. The provisions of 780 CMR 1813.2, 1813.4 and 1813.5.1 shall not apply in this case.

1813.1.2 Underfloor space: The finished ground level of an underfloor space such as a crawl space shall not be located below the bottom of the footings. Where there is evidence that the ground water table rises to within six inches (152 mm) of the ground level at the outside building perimeter or where there is evidence that the surface water does not

readily drain from the building site, the ground level of the underfloor space shall be as high as the outside finished ground level, unless an approved drainage system is provided. The provisions of 780 CMR 1813.2, 1813.3, 1813.4, 1813.5 and 1813.6 shall not apply in this case.

1813.2 Ground water table investigation: The owner or applicant shall perform a subsurface soil investigation in accordance with 780 CMR 1802.0 to determine the possibility of the ground water table rising above the proposed elevation of the floor or floors below grade.

Exception: A subsurface soil investigation shall not be required where:
1. Waterproofing is to be provided;
2. Satisfactory data from adjacent areas are available which demonstrate that ground water has not been a problem; or
3. Floodproofing is to be provided in accordance with 780 CMR 3107.0.

1813.2.1 Ground water control: Where the ground water table is lowered and maintained at an elevation not less than six inches (152 mm) below the bottom of the lowest floor, the floor and walls shall be dampproofed in accordance with 780 CMR 1813.3. The design of the system to lower the ground water table shall be based upon accepted principles of engineering which shall consider, but not necessarily be limited to: permeability of the soil; rate at which water enters the drainage system; rated capacity of pumps; head against which pumps are to pump; and the rated capacity of the disposal area of the system. The design shall also take into account any adverse impacts on utilities, structures or other facilities in the vicinity which would result from the lowering of groundwater levels.

1813.3 Dampproofing required: Where hydrostatic pressure will not occur as determined by 780 CMR 1813.2, floors and walls for other than wood foundation systems shall be dampproofed in accordance with 780 CMR 1813.0. Wood foundation systems shall be constructed in accordance with NFoPA TR7 listed in ***Appendix A***.

1813.3.1 Floor applications: The required dampproofing materials shall be installed between the floor and the base course required by 780 CMR 1813.5.1, except where a separate floor is provided above a concrete slab.

1813.3.1.1 Floor dampproofing materials: Where installed beneath the slab, dampproofing shall consist of not less than 6-mil (.006 inch; 152 µm) polyethylene with joints lapped not less than six inches (152 mm), or other approved methods or materials. Where permitted to be installed on top of the slab, dampproofing shall consist of mopped-on bitumen, not less than 4-mil (.004 inch; 102 µm) polyethylene, or other approved methods or materials. Joints in the membrane shall be lapped and sealed in accordance with the manufacturer's installation instructions.

1813.3.2 Walls: Dampproofing materials shall be installed on the exterior surface of walls and shall extend from the top of the footing to above ground level.

1813.3.2.1 Surface preparation of walls: Prior to application of dampproofing materials on concrete walls, all holes and recesses resulting from the removal of form ties shall be sealed with a bituminous material or other approved methods or materials. Unit masonry walls shall be parged on the exterior surface below ground level with not less than _ inch (10 mm) of portland cement mortar. The parging shall be coved at the footing.

Exception: Parging of unit masonry walls is not required where a material is approved for direct application to the masonry.

1813.3.2.2 Wall dampproofing materials: Dampproofing shall consist of a bituminous material, three pounds per square yard of acrylic modified cement, _-inch coat of surface-bonding mortar complying with ASTM C887 listed in ***Appendix A***, any of the materials permitted for waterproofing by 780 CMR 1813.4.2.2, or other approved methods or materials.

1813.4 Waterproofing required: Where the ground water investigation required by 780 CMR 1813.2 indicates that a hydrostatic pressure condition exists, walls and floors shall be waterproofed in accordance with 780 CMR 1813.4.

1813.4.1 Floors: Floors required to be waterproofed shall be of concrete, designed and constructed to withstand the hydrostatic pressures to which the floors will be subjected.

1813.4.1.1 Floor waterproofing materials: Waterproofing shall be accomplished by placing a membrane of rubberized asphalt, butyl rubber, neoprene, or not less than 6-mil (.006 inch; 152 µm) polyvinyl chloride or

polyethylene with joints lapped not less than six inches (152 mm) or other approved materials under the slab. Joints in the membrane shall be lapped and sealed in accordance with the manufacturer's installation instructions.

1813.4.2 Walls: Walls required to be waterproofed shall be of concrete or masonry and shall be designed and constructed to withstand the hydrostatic pressures and other *lateral loads* to which the walls will be subjected.

1813.4.2.1 Surface preparation of walls: Prior to the application of waterproofing materials on concrete or masonry walls, the walls shall be prepared in accordance with 780 CMR 1813.3.2.1.

1813.4.2.2 Wall waterproofing materials: Waterproofing shall be applied from the bottom of the wall to not less than 12 inches (305 mm) above the maximum elevation of the ground water table. The remainder of the wall shall be dampproofed in accordance with 780 CMR 1813.3.2.2. Waterproofing shall consist of two-ply hot-mopped felts, not less than 6-mil (.006-inch; 152-µm) polyvinyl chloride, 40-mil (.040-inch; 1 mm) polymer-modified asphalt, 6-mil (.006-inch; 152-µm) polyethylene or other approved methods or materials capable of bridging nonstructural cracks. Joints in the membrane shall be lapped and sealed in accordance with the manufacturer's installation instructions.

1813.4.3 Joints and penetrations: Joints in walls and floors, joints between the walls and floor, and penetrations of the wall and floor shall be made water tight utilizing approved methods and materials.

1813.5 Subsoil drainage system: Where a hydrostatic pressure condition does not exist, dampproofing shall be provided and a base shall be installed under the floor and a drain installed around the foundation perimeter. A subsoil drainage system designed and constructed in accordance with 780 CMR 1813.2.1 shall be deemed adequate for lowering the groundwater table.

1813.5.1 Floor base: Floors of *basements*, except as provided for in 780 CMR 1813.1.1, shall be placed over a base course not less than four inches (102 mm) in thickness that consists of gravel or crushed stone containing not more than 10% of material that passes through a No. 4 sieve.

Exception: Where a site is located in well- drained gravel or sand/gravel mixture soils, a floor base is not required.

1813.5.2 Foundation drain: A drain shall be placed around the perimeter of a foundation that consists of gravel or crushed stone containing not more than 10% material that passes through a No. 4 sieve. The drain shall extend a minimum of 12 inches (102 mm) beyond the outside edge of the footing. The thickness shall be such that the bottom of the drain is not higher than the bottom of the base under the floor, and that the top of the drain is not less than six inches (152 mm) above the top of the footing. The top of the drain shall be covered with an approved filter membrane material. Where a drain tile or perforated pipe is used, the invert of the pipe or tile shall not be higher than the top of the lowest floor elevation. The top of joints shall be protected with an approved filter membrane material. The pipe or tile shall be placed on not less than two inches (51 mm) of gravel or crushed stone complying with 780 CMR 1813.5.1, and shall be covered with not less than six inches (152 mm) of the same material.

1813.5.3 Drainage disposal: The floor base and foundation perimeter drain shall discharge by gravity or mechanical means into an approved drainage system that complies with the plumbing code (248 CMR) listed in ***Appendix A***.

Exception: Where a site is located in well-drained gravel or sand/gravel mixture soils, a dedicated drainage system is not required.

1813.6 Placement of backfill: The excavation outside the foundation shall be backfilled with soil that is free of organic material, construction debris and large rocks. The backfill shall be placed in lifts and compacted in a manner which does not damage the foundation, the waterproofing or the dampproofing material.

1813.7 Site grading: The ground immediately adjacent to the foundation shall be sloped away from the building at a slope of not less than one unit vertical in 12 units horizontal (1: 12) for a minimum distance of eight feet (2.4 m) measured perpendicu-lar to the face of the wall or an approved alternate method of diverting water away from the foundation shall be used. The procedure utilized to establish the final ground level adjacent

to the foundation shall account for all additional settlement of the backfill.

1813.8 Erosion protection: Where water impacts the ground from the edge of the roof, downspout, scupper or other rainwater collection or diversion device, provisions shall be made to prevent soil erosion and direct the water away from the foundation.

780 CMR 1814.0 MAT, RAFT AND FLOAT FOUNDATIONS

1814.1 General: Mat, raft and float foundations shall only be used where the applied loads of the building or structure are so arranged as to result in practically uniformly balanced loading, and the soil immediately below the mat is of uniform loadbearing capacity. The characteristics of the soil under the mat or raft shall be considered in the analysis of loading on mats and other continuous footings, and due allowance shall be made for possible concentrated soil pressures under heavily loaded columns.

1814.2 Settlement Analysis: The design of floating foundations shall include a settlement analysis in accordance with the provisions on 780 CMR 1805.5.

780 CMR 1815.0 PIER FOUNDATIONS

1815.1 General: A foundation pier is here defined as a structural member which extends to satisfactory bearing materials to develop support by end bearing and/or friction in those materials. The pier shall be constructed by advancing a hole to the required depth using non-displacement methods and filling the hole with reinforced or plain concrete. 780 CMR 1815.0 includes foundation types referred to as drilled piers, drilled shafts and caissons, including both circular and non-circular foundation elements. Uncased piles installed by the hollow stem auger method are included in 780 CMR 1820.2, Augered uncased piles.

The minimum dimension of the pier shall be no less than 12 inches (305 mm). The base may be enlarged by belling to increase the bearing area.

1815.1.1 Special types of piers: Types of piers not specifically covered by the provisions of 780 CMR 1815.0 may be permitted, subject to the approval of the code official, upon the submission of acceptable test data and design and construction information prepared by a *registered design professional* stating that the pier installation is adequate to fulfill the design requirements.

1815.2 Seismic design:

1815.2.1 Foundation ties: Pier foundations shall be interconnected by ties capable of resisting, in tension or compression, a force equal to 10% of the larger column *dead* plus *live load*. Individual tie beams are not required when it is demonstrated that equivalent restraint will be provided by structural members within slabs on grade or reinforced concrete slabs on grade or confinement by competent rock, hard cohesive soils, dense granular soils or other approved means.

1815.2.2 Seismic reinforcement: Cast in place concrete piers shall have minimum reinforcement of 0.25% of the minimum pier design cross-sectional area for buildings assigned to *Seismic Performance Category C*, and a minimum reinforcement of 0.50% for buildings assigned to *Seismic Performance Category D* in accordance with 780 CMR 1612.2.7. The minimum pier design cross-sectional area is that area determined in accordance with 780 CMR 1815.6. (The actual constructed cross-sectional area may be larger.) The reinforcing shall be placed in the top _ of the pier length or extend ten feet (3 m) from the top of the pier, whichever is the longer length.

For *Seismic Performance Category C* buildings, the pier reinforcing shall be a minimum of four longitudinal bars with closed ties, or equivalent spirals, having a minimum diameter of ¼ inch. The ties shall be provided at a maximum spacing of 16 times the longitudinal reinforcing bar diameter and shall enclose an area of concrete sufficient to confine the minimum design cross-sectional concrete area. The maximum tie spacing in the top two feet (0.6 m) of the pier length shall be four inches (102 mm). Tie detailing shall be in accordance with 780 CMR 1903.4.

For *Seismic Performance Category D* buildings, the pier reinforcing shall be a minimum of four longitudinal bars with closed ties, or equivalent spirals, having a minimum diameter of _ inch, for piers with a diameter of 20 inches (508 mm) or less; and a minimum tie diameter of ½ inch, for piers with a diameter more than 20 inches (508 mm). The ties shall be provided at a maximum spacing of eight times the longitudinal reinforcing bar diameter. The maximum tie spacing in the top four feet (1.2 m) of the pier length shall be three inches (76 mm). Tie detailing shall be in accordance with 780 CMR 1903.5.

Exception: Pier ties or spirals are not required where permanent metal casing (steel pipe, steel tube or spiral-welded steel shell) is used, provided the casing has minimum

thickness as follows: for *seismic Performance Category C* buildings, 0.058 inch (1.5 mm), and for *Category Performance Category D* buildings, 0.070 inch (1.8 mm). The steel casing must be adequately protected from corrosion due to soil, changing water levels, or other subgrade conditions indicated by the site soil investigation.

1815.2.3 Pier cap connection: All piers shall be connected to the pier cap so that pier reinforcement is embedded in the cap for a distance equal to the development length as specified in ACI 318 listed in ***Appendix A***. Field-placed dowels anchored in the concrete piers are acceptable. The development length to be provided is the full development length of the reinforcement for compression without reduction in length for excess area.

1815.2.4 Alternative detailing: Alternative measures for laterally confining concrete and maintaining toughness and ductile-like behavior at the top of the pier shall be permitted provided consideration is given to forcing the hinge to occur in the confined region.

1815.3 Installation: In unstable soils, a temporary casing or slurry shall be used to stabilize the excavation. When a slurry is used to stabilize the excavation, the level and quality of the slurry shall be monitored and controlled to maintain stability of the shaft and the bearing surface.

1815.4 Enlarged bases: Bell-shaped bases shall have a minimum edge thickness of four inches (102 mm). The bell roof shall slope not less than 60° with the horizontal unless the base is designed in accordance with ACI 336 listed in ***Appendix A*** (hereinafter ACI 336).

1815.5 Placement of concrete: Concrete may be dropped into the pier from the ground surface provided no more than three inches (76 mm) of water remains in the bottom and the concrete will free-fall vertically without obstruction. The concrete shall be placed in a rapid, continuous
1815.7 Alignment: When the center of the cross section of a foundation pier at any level deviates from the resultant of all forces more than 1/50 of its height, or more than 1/10 of its diameter, it shall be reinforced as provided in ACI 336. The restraining effect of the surrounding soil may be taken into account.

1815.8 Allowable bearing pressure: The allowable bearing pressure on the bottom of the pier shall be in accordance with 780 CMR 1804.3 Additional load may be carried by using higher bearing pressures than allowed by 780 CMR operation and controlled such that the concrete does not segregate.

1815.5.1 No piers shall be installed near a concreted pier until the concrete has set sufficiently to avoid damage to the concreted pier.

1815.5.2 For piers without enlarged bases, concrete or grout may be placed through still water or slurry. A properly operated tremie or pumping method shall be used. Samples of the slurry shall be tested to determine the properties prior to placing concrete in each pier. The quality, consistency, and density of the slurry shall be controlled to ensure that there will be free-flow of concrete from the tremie pipe. The concrete must be placed such that all water, slurry and contaminated concrete below design cutoff level is displaced.

1815.5.3 For piers with enlarged bases, the concrete may be placed under slurry, based upon the recommendations of a *registered design professional* and with the approval of the code official. The specific soil or rock conditions, equipment and procedures used shall be taken into account.

1815.5.4 A suitable method shall be employed to verify that the entire length of the shaft is completely filled with concrete. Such means shall include the ability to determine the incremental volumes of concrete installed in relation to calculated shaft volume.

1815.6 Design stresses: Foundation piers may be designed as concrete columns with continuous lateral support below the soil level. The unit compressive stress in the concrete shall not exceed 33% of the 28 day strength of the concrete or 1,600 psi, whichever is less. The unit compressive stress in the steel reinforcement or the permanent steel casing shall not exceed 40% of the yield strength of the steel or 24,000 psi, whichever is less. Permanent steel casing which is used as structural reinforcement shall be protected against corrosion in accordance with 780 CMR 1816.4.1.

1804.3 and/or by friction on the sides of the pier embedded in suitable bearing material based on recommendations by a *registered design professional* and subject to the approval of the code official. Such recommendations shall be based on the results of load tests or other suitable tests or analyses carried out to measure side friction and/or end bearing of piers installed in the same bearing stratum.

1815.9 Minimum spacing: The minimum center-to-center spacing between adjacent piers

designed for friction support shall be not less than two times the shaft diameter.

1815.10 Special provisions: For piers with shaft diameter less than 24 inches (610 mm), the following special provisions shall apply:

1815.10.1 For piers with temporary casing extending to the bottom, the concrete may be poured from the top in accordance with 780 CMR 1815.5.

1815.10.2: For all other cases, piers shall be filled from the bottom upward through a tremie or concrete pump tube in accordance with 780 CMR 1815.5.2

1815.11 Records: The owner shall engage a *registered design professional* to monitor the installation of the piers. The design professional or his representative, qualified by training and experience, shall be present at all times while foundation piers are being installed, to observe and test the bearing material in place, to verify the pier dimensions and to observe concrete placement. When direct inspection of the bearing surface is impossible, a suitable method shall be employed to verify the condition of the bearing material and to make the measurements and tests. Records of all observations, tests and dimensions shall be signed by the *registered design professional* and a copy shall be filed in the office of the code official.

780 CMR 1816.0 PILE FOUNDATIONS

1816.1 Investigation: Pile foundations shall be designed and installed on the basis of a foundation investigation and report conducted in accordance with 780 CMR 1802.0. The investigation shall include borings, test pits or other subsurface explorations at locations and depths sufficient to determine the position, thickness and adequacy of the loadbearing soils and demonstrate that there are no compressible soil deposits below the bearing stratum which would adversely affect the structure, *except* where sufficient data upon which to base the design and installation are available from other sources. In addition, the building site shall be investigated for all conditions which might promote deterioration of pile foundations, in order to satisfy the requirements of 780 CMR 1816.4. The investigation and report shall include, but not be limited to, the following:

1. Recommended pile types and installed capacities;
2. Driving criteria;
3. Installation and field inspection procedures;
4. Pile load test requirements;
5. Durability of pile materials; and
6. Designation of loadbearing stratum or strata.

1816.2 Special piles: Types of piles not specifically covered by the provisions of 780 CMR 1816.0 may be permitted, subject to the approval of the code official, upon the submission of acceptable test data and design and construction information prepared by a *registered design professional* stating that the pile installation is adequate to fulfill the design requirements.

1816.3 Seismic Design

1816.3.1 Seismic reinforcement: Piles shall have minimum longitudinal reinforcement and confining reinforcement in accordance with the provisions for specific pile types set forth in 780 CMR 1818.0 through 780 CMR 1824.0.

Where a minimum length for reinforcement or the extent of closely spaced confinement reinforcement is specified at the top of the pile, provisions shall be made so that those specified lengths or extents are maintained after pile cutoff.

Where seismic reinforcement at the top of the pile is required, alternative measures for laterally confining concrete and maintaining toughness and ductile-like behavior at the top of the pile shall be permitted provided consideration is given to forcing the hinge to occur in the confined region.

1816.3.2 Pile bending seismic design: Piling for buildings assigned to *Seismic Performance Category D*, in accordance with 780 CMR 1612.2.7, shall be designed for the maximum imposed curvatures resulting from seismic forces on free-standing piles where the piles are located in loose granular soils or in soil-profile type S3 or S4, in accordance with 780 CMR 1612.4.1. The piles shall be designed and detailed in accordance with the special moment frame requirements of 780 CMR 1903.3.3 or 780 CMR 2203.2 for a length equal to 120% of the flexural length. The flexural length shall be the distance from the point of fixity to the pile cap.

1816.3.3 Pile cap seismic connection: Piles shall be connected to the pile caps in accordance with the provisions for specific pile types set forth in 780 CMR 1818.0 through 780 CMR 1824.0.

1816.3.4 Pile foundation seismic ties: Piles or pile caps shall be interconnected by ties capable of resisting, in tension or compression, a force equal to 10% of the larger column dead plus live load. Individual tie beams are not required when it is demonstrated that equivalent restraint will be provided by structural members within slabs on grade or reinforced concrete slabs on grade or confinement by competent rock,

cohesive soils, dense granular soils or other approved means.

1816.4 Protection of pile materials: Where boring records, previous experience, or site conditions indicate possible deleterious action on pile materials because of soil constituents, changing water levels or other factors, the pile materials shall be adequately protected by approved materials, methods or processes. Protective materials shall be applied to the piles so as not to be rendered ineffective by driving.

1816.4.1 Steel and steel-concrete piles: At locations where steel and steel-concrete piles will be in contact with any material which is corrosive to the steel, one of the following procedures shall be used for protection, or any other method which will satisfy the requirements of the code official:

1. Remove all objectionable material.
2. Effectively protect the steel surface from pile cutoff grade to a grade 15 feet (4.6 m) below the bottom of the objectionable material by means of:
   a. cathodic protection as approved by the code official;
   b. an approved encasement of not less than three inches (76 mm) of dense concrete;
   c. an effective protective coating subject to the approval of the code official; or
   d. providing an excess steel thickness of _ inch (3.2 mm) beyond design requirements on all exposed steel surfaces.

1816.4.2 Timber piles: The preservative treatment of timber piles shall comply with the provisions of 780 CMR 1822.2.

1816.5 Lateral support: Any soil shall be deemed to afford sufficient lateral support to permit the design of any type of pile as a short column. When piles are driven through soil which will be removed subsequent to the completion of the foundation, the resistance offered by such material shall not be considered to contribute to the lateral supporting capacity.

1816.5.1 Column action: The portion of a pile that is not laterally supported shall be designed as a column in accordance with 780 CMR 19 taking into consideration the conditions of end fixity.

1816.6 Group action: In cohesive soils, the compressive load capacity of a group of friction piles shall be analyzed by a generally accepted engineering method, and, where such analysis indicates, the individual allowable pile load shall be reduced accordingly.

1816.7 Stability:

1816.7.1 Wall foundations: All piles in wall foundations shall be staggered about the center of gravity of the wall load at a minimum distance of ½ the pile top diameter therefrom. A foundation wall restrained laterally so as to ensure stability both during and after construction may be supported by a single row of piles.

1816.7.2 Columns: Individual columns supported on piles shall be designed for eccentricity between the column and the centroid of the supporting piles equal to a minimum of three inches (76 mm) or the actual eccentricity, whichever is greater. The design shall account for such eccentricity through one of the following methods:

a. By supporting the column on a minimum of three piles in a triangular pattern.
b. By designing walls, grade beams or structural floors to resist the bending moment induced by the eccentricity.
c. By designing the piles, column or both to resist the bending moment induced by the eccentricity and providing adequate lateral restraint at the top of the piles to resist the lateral thrust due to the bending moment.

1816.8 Structural integrity: Piles shall be installed in such a manner and sequence as to prevent distortion or damage to piles being installed or already in place, to the extent that such distortion or damage affects the structural integrity of the piles.

When piles have been damaged in driving, or have been driven in locations and alignment other than those indicated on the plans, or have capacities less than required by the design, the affected pile groups and pile caps shall be investigated, and if necessary, the pile groups or pile caps shall be redesigned or additional piles shall be driven to replace the defective piles.

1816.9 Spacing: The minimum center-to-center spacing of piles shall be not less than twice the average diameter of a round pile, nor less than 1¾ times the diagonal dimension of a rectangular pile. When driven to or penetrating into rock, the spacing shall be not less than 24 inches (610 mm). When receiving principal support from end-bearing on materials other than rock or through frictional resistance, the spacing shall be not less than 30 inches (762 mm) or as provided in 780 CMR 1820.4.6 for Pressure Injected Footings.

1816.10 Splices: Splices shall be avoided insomuch as practicable. When used, slices shall be constructed so as to provide and maintain true alignment and position of the component parts of

the pile during installation and subsequent thereto, and shall be of adequate strength to transmit the vertical and *lateral loads* and moments occurring at the location of the splice during driving and under service loading. Splices shall develop not less than 50% of the capacity of the pile in bending. Additionally, all pile splices occurring in the upper ten feet (3 m) of the embedded portion of the pile shall be capable of resisting at allowable working stresses the moment and shear that results from an assumed eccentricity of the pile load of three inches (76 mm); or the pile shall be braced in accordance with 780 CMR 1816.7 to other piles that do not have splices in the upper ten feet (3 m) of embedment.

1816.11 Pile caps: Pile caps shall be of reinforced concrete. The soil immediately below the pile cap shall not be considered as carrying any vertical load. The tops of all piles shall be embedded not less than three inches (76 mm) into pile caps, and the caps shall extend at least four inches (102 mm) beyond the edges of all piles. The tops of all piles shall be cut back to sound material before capping.

1816.12 Pre-excavation: Jetting, augering and other methods of pre-excavation must be approved by the code official and carried out in the same manner as used for piles subject to load test and in a manner which will not impair the carrying capacity of the piles already in place or the safety of existing adjacent structures. Pre-excavation shall be of the same method as carried out on piles subject to load tests. Immediately after completion of jetting or augering, the pile shall be advanced to the maximum depth of pre-excavation and driven below this depth to the required load resistance. Where load tests are required, pre-excavation of test piles will be of the same manner as proposed for production piles.

1816.13 Inspection: The owner shall engage a *registered design professional* who shall submit his qualifications in writing to the code official. This design professional, or his representative, who must be qualified by experience and training, shall be present at all times while piles are being driven to observe all work in connection with the piles. The design professional or his representative shall make an accurate record of the material and the principal dimensions of each pile, of the weight and fall of the ram, the type, size and make of hammer, cushion blocks, the number of blows per minute, the energy per blow, the number of blows per inch for the last six inches (150 mm) of driving, together with the grades at point and cutoff and any other pertinent details. A copy of these records shall be signed by the *registered design professional*, and filed in the office of the code official.

1816.14 Identification: All pile materials shall be identified for conformity to the specified grade with this identification maintained continuously from the point of manufacture to the point of installation or shall be tested by an *approved agency* to determine conformity to the specified grade and the *approved agency* shall furnish an affidavit of compliance to the code official .

1816.15 Pile location plan: A plan showing the location and designation of all piles by an identification system shall be filed with the code official prior to installation of such piles. All detailed records for individual piles shall bear an identification corresponding to that shown on the plan.

1816.16 Use of existing piles: Piles that have previously supported a partially or fully demolished structure shall not be used for support of new construction unless satisfactory evidence is submitted to the code official which indicates that the piles have not been adversely impacted by the demolition, are sound, have adequate capacity to support the new design loads, and meet all of the requirements of 780 CMR. The capacities of such piles shall be determined by analyses, load testing or redriving. The design load applied to such piles shall not exceed the greater of the following values:

a. actual sustained load determined to have been previously supported satisfactorily by the piles, up to a maximum of 120 tons

b. the documented, as-built design capacity of the piles, as confirmed by prior load testing

c. design capacity determined by analyses and confirmed by new load testing or by redriving per 780 CMR 1817.3.1 on one or more piles representative of each configuration (s) of pile and subsurface conditions.

1816.17 Pile driveability: Pile cross sections shall be of sufficient size and strength to withstand handling and driving stresses without damage to the pile and to provide sufficient stiffness to transmit the required driving forces. Driven piles of uniform cross section or tapered piles shall have a minimum nominal diameter of eight inches (200 mm) except as provided in 780 CMR 1820.6.4 for small diameter grouted piles, 780 CMR 1822.3.3 for timber piles and 780 CMR 1821.1 for precast concrete piles. Tapered shoes or points of lesser dimensions may be attached to the pile unit.

1816.18 Pile heave: Adequate provision shall be made to observe pile heave. Accurate reference points shall be established on each pile immediately after installation; for cast-in-place piles with unfilled corrugated shells, the reference point shall be at the bottom of the pile. If, following the installation of other piles in the

vicinity, heaving of ½ inch (13 mm) or more occurs, the heaved piles shall be re-driven to develop the required capacity and penetration, or the capacity of the pile may be verified by load tests in accordance with 780 CMR 1817.4.

1816.19 Settlement analysis: The settlement of individual piles or groups of piles shall be estimated based upon approved methods of analysis and in accordance with 780 CMR 1805.2.2. The predicted settlement shall neither cause harmful distortion of or instability in the structure, nor cause any stresses to exceed allowable values.

1816.20 Use of vibratory drivers: Vibratory drivers shall only be used to install piles where the pile load capacity is verified by load tests in accordance with 780 CMR 1817.4. The installation of production piles shall be controlled according to power consumption, rate of penetration or other approved means that assure pile capacities equal to or exceeding those of the test piles.

1816.21 Installation sequence: Piles shall be installed in such sequence as to avoid compacting the surrounding soil to the extent that other piles cannot be installed properly, and to prevent ground movements that could damage adjacent structures.

780 CMR 1817.0 ALLOWABLE PILE LOADS

1817.1 General: The allowable load on piles shall be determined by the applicable formulas complying with accepted engineering practice or load tests as stated herein. The maximum load capacity shall be limited by the supporting capacity as obtained from bearing upon or embedment in bearing materials as defined in 780 CMR 1804.0 and 1805.0, but the load shall not exceed the capacity of the pile designed in accordance with the provisions of 780 CMR 1817.0 and the Code provisions for the construction materials involved.

The allowable load on a pile shall not be limited to load obtained by multiplying its point area by the allowable bearing pressure given in 780 CMR 1804.3.

1817.2 Piles in subsiding areas: Where piles are driven through subsiding fills or other subsiding strata and derive support from underlying firmer materials, the downward friction forces which are imposed on the piles by the subsiding upper strata shall be included in the design.

1817.3 Determination of allowable load: In the absence of pile load tests performed in accordance with 780 CMR 1817.4, the load on a single pile, except for the pile types covered in 780 CMR 1820.2 (augered uncased piles), 780 CMR 1820.4 (pressure injected footings) and 780 CMR 1824.0 (steel-core caissons), shall not exceed the higher of the two values determined in accordance with 780 CMR 1817.3.1 (driving formula) or 780 CMR 1817.3.2 (friction formula in clay). Loads on jacked piles shall be determined in accordance with 1817.3.3.

1817.3.1 Driving formula:

1. Where the design load capacity of the pile does not exceed 50 tons, the allowable load may be computed by means of the following driving formula:

$$R = \frac{2E}{S + C}$$

where--

R = allowable pile load in pounds;
E = energy per blow in foot-pounds;
S = penetration of last blow or average penetration of last few blows expressed in inches; and
C = constant equal to 1.0 for drop hammer and 0.1 for steam or air hammer.

2. When the design load capacity of a pile exceeds 50 tons, the required driving resistance shall be increased above that required by the driving formula in 780 CMR 1817.3.1 based on load tests or past experience under similar conditions.
3. The value of S must be determined with the hammer operating at 100% of the rated number of blows per minute for which the hammer is designed.
4. Any driving resistance developed in strata overlying the bearing material shall be discounted.
5. If the driving of the pile has been interrupted for more than one hour, the value of S shall not be determined until the pile is driven at least an additional 12 inches (305 mm), except when it encounters refusal on or is in a material of Classes 1 through 6.
6. When any pile is driven through a layer of gravel, sand or hard clay exceeding five feet in thickness, and through an underlying soft stratum to reach the bearing stratum, the bearing capacity shall not be determined in accordance with the driving formula, unless jetting is used during the entire driving of the pile through the layer of gravel, sand or hard clay or unless a hole is pre-excavated through said layer for each pile.

1817.3.2 Friction formula in clay: Where the design load does not exceed 22 tons, the allowable load on a pile stopped in soil of Material Class 10 (Table 1804.3) of medium to hard consistency may be based on a friction value of 500 psf of embedded pile surface. Higher design loads or other friction values shall be determined by pile load tests in accordance with 780 CMR 1817.4 or 1817.7.

The embedded length shall be the length of the pile below the surface of the Class 10 soil or below the surface of immediately overlying satisfactory bearing material. The area of embedded pile surface shall be computed by multiplying the embedded length by the perimeter of the smallest circle or polygon that can be circumscribed around the average section of the embedded length of the pile. The method of determining the allowable load described in 780 CMR 1817.3.2 shall not be used for a pile in which the drive pipe is withdrawn or for piles which are driven through the clay to or into firmer bearing materials.

In case these piles are in clusters, the allowable load shall be computed for the smaller of the following two areas: the sum of the embedded pile surfaces of individual piles; or the area obtained by multiplying the perimeter of the polygon circumscribing the cluster at the surface of the satisfactory bearing material by the average embedded length of the piles.

1817.3.3 Jacked piles:

1. Not less than 10% of jacked piles shall be load-tested to twice the design load (load test piles). All other jacked piles shall be founded in the same bearing stratum as the load test piles and shall be proof-loaded to 125% of design load (production piles).
2. For production piles, the 125% of design load shall be maintained for at least 30 minutes. Acceptability criteria: during final 15 minutes of load, the rate is not progressive (plot is linear or decreasing when settlement is plotted against logarithm of time); and the rate of settlement is equal to or less than that observed for load test piles during the corresponding time period under 125% of design load.
3. Settlement readings shall be plotted after one, two, four, eight, and 15 minutes, and at 15-minute intervals thereafter. Load shall be maintained on production piles until acceptability criteria are met.
4. For load test piles, the load shall be applied directly to 125% of design load and maintained for not less than 30 minutes, and until the settlement rate is not progressive (as defined above). Load shall then be increased to twice the design load and maintained constant for not less than four hours. Settlement during the four hour period shall not exceed 0.050 inches (1.3 mm).

In the event that settlement exceeds 0.050 inches (1.3 mm) in four hours, the pile shall be deemed unacceptable for ½ of the final load. The allowable load on the rejected pile may be established by performing an additional load test at the lesser design load. The design load shall not exceed ½ the load maintained for a four hour period during which time settlement did not exceed 0.050 inches (1.3 mm).

1817.4 Compression load test: Where the design load for any pile is in doubt or where the proposed design load for any pile, including pressure injected footings, exceeds 50 tons or exceeds the value determined in accordance with 780 CMR 1817.3.2 (friction formula in clay), one or more pile load tests shall be performed on representative piles in accordance with 780 CMR 1817.0.

The results of the load test can be applied to other piles within the area of substantially similar subsoil conditions as that for the test pile, providing the performance of the test pile has been satisfactory and the remaining piles are of the same type, shape and size as the test pile and are installed using the same methods and equipment and are driven into the same bearing strata as the load-tested pile to an equal or greater penetration resistance.

For design loads between 50 and 120 tons, pile load tests may be waived by the code official, where justified, upon submittal of substantiating data prepared by a *registered design professional* which include experience and/or performance records for the proposed pile installation under similar soil and loading conditions.

1817.4.1 Required test load: A single pile shall be load-tested to not less than twice the allowable design load. When two or more piles are to be tested as a group, the total load shall be not less than 1½ times the allowable design load for the group.

In no case should the load reaching the top of the bearing stratum under maximum test load for a single pile or pile group be less than the following:

Case A-piles designed as end-bearing piles: 100% of the allowable design load.

Case B-piles designed as friction piles: 150% of the allowable design load.

For piles designed as combination end-bearing and friction piles, Case A applies if the pile is designed to support more than 50% of its design in bearing; otherwise, Case B applies.

1817.4.2 Internal instrumentation: The test pile shall be instrumented in accordance with the requirements in paragraph 4.4.1 of ASTM D1143 listed in ***Appendix A*** (hereinafter ASTM D1143) to enable measurement or computation of the load in the pile where it enters the bearing stratum. For piles containing concrete, instrumentation shall be installed in the test pile to permit direct measurement of the elastic modulus of the pile.

This requirement is waived for the following cases:

1. The test pile is installed within a casing that extends to within ten feet above the bearing stratum.
2. The pile to be tested has been functioning satisfactorily under load for a period of one year or more.
3. The pile is 30 feet long or less and no appreciable load will be supported above the bearing stratum.

1817.4.3 Loading procedure: Pile load tests shall be conducted in accordance with ASTM D1143, Standard Method of Testing Piles Under Static Axial Compressive Load, except that Section 5, Loading Procedures, shall be deleted and replaced by the following provisions:

1. Apply 25% of the allowable design load every ½ hour. Longer time increments may be used, but each time increment should be the same. In no case shall a load be changed in the rate of settlement is not decreasing with time.
2. At 200% of the allowable design load (or 150% for pile groups), maintain the load for a minimum of one hour and until the settlement (measured at the lowest point on the pile at which measurements are made) over a one-hour period is not greater than 0.01 in.
3. Remove 50% of the design load every 15 minutes until zero load is reached. Longer time increments may be used, but each should be the same.
4. Measure rebound at zero load for a minimum of one hour.
5. For each load increment or decrement, take readings at the top of the pile and on the internal instrumentation at one, two, four, eight and 15 minutes and at 15-minute intervals thereafter.

A load greater than 200% of the allowable design load (or 150% of the allowable design load for pile groups) may be applied at the top of the pile, using the above loading procedure, to ensure that 780 CMR 1817.4.1 is fulfilled. Other optional methods listed in ASTM D1143 may be approved by the code official upon submittal in advance of satisfactory justification prepared by a *registered design professional* who is qualified in this field.

1817.4.4 Selection of design load: Provided that the allowable design load does not exceed the load allowed in 780 CMR 1817.0 for the type of pile and provided that the allowable design load does not exceed 100% of the load supported in the bearing stratum (or _ of the load supported in the bearing stratum for friction piles or pile groups) when the maximum test load is applied, then the allowable design load shall be the greater of the following:

1. Allowable design load based on settlement during loading: 50% of the applied test load which causes a gross settlement at the pile cutoff grade equal to the sum of: a) the theoretical elastic compression of the pile in inches assuming all the load on the butt is transmitted to the tip, plus b) 0.15 inch (3.8 mm), plus c) 1% of the pile tip diameter or pile width in inches. If the settlements are so small that the load-settlement curve does not intersect the failure criterion, the allowable design load shall be 50% of the maximum test load.
2. Allowable design load based on the net settlement after rebound: 50% of the applied test load which results in a net settlement at the top of the pile of ½ inch (13 mm) after rebound for a minimum of one hour at zero load.

1817.5 Use of higher allowable stresses: Higher stresses than those permitted in 780 CMR 1817 for various pile materials may be approved by the code official based upon the submission of substantiating data and analyses which justify such higher stresses. The data shall be presented in a report prepared by a *registered design professional* experienced in geotechnical aspects of foundation design and shall include, as applicable: the results of the soil investigation, dynamic analyses of the pile behavior, pile load tests, analyses of load transfer during testing and prediction of pile performance during long term service.

1817.6 Lateral load tests: The allowable load on piles subject to *lateral load* shall be verified by test unless it is waived by the code official. Pile load tests may be waived by the code official, where justified, upon submittal of substantiating data which include experience and/or performance records for pile installations under similar soil and loading conditions prepared by a *registered design professional* experienced in geotechnical aspects of foundation design.

1817.6.1 Required test load: A single pile shall be load tested to not less than 200% of the design *lateral load.*

1817.6.2 Test setup and loading procedure: The load test setup instrumentation and loading procedure shall be in accordance with ASTM D3966 listed in ***Appendix A***.

1817.6.3 Selection of design load: The design load shall be selected by the responsible *registered design professional,* based upon

interpretation of the load-deflection data from the load test.

1817.7 Tension load tests: The allowable load on piles in tension shall be verified by test unless it is waived by the code official. Pile load test may be waived by the code official, where justified, upon submittal of substantiating data which includes experience and/or performance records for pile installations under similar soil and loading conditions prepared by a *registered design professional* experienced in the geotechnical aspects of foundation design.

1817.7.3 Selection of design load: Provided the allowable design load does not exceed the allowable stresses in the pile materials, the allowable design load shall be the lower of the following:

1. 50% (for transient loads) or 40% (for sustained loads) of the applied test load which results in a net upward movement of ½ inch at the top of the pile after removal of the maximum test load (The gross upward movement minus the rebound movement).
2. 50% (for transient loads) or 40% (for sustained loads) of the applied test load which results in continuous upward movement with no increase in load.

1817.8 Bearing capacity: Individual piles and groups of piles shall develop ultimate load capacities of at least twice the design working loads in the designated bearing layers. Where weaker materials underlie the load bearing material into which the piles are driven, the allowable pile load shall be limited by the provision that the vertical pressures in such underlying materials produced by the loads on all piles in a foundation shall not exceed the allowable bearing pressures of such materials as provided in Table 1804.3 or as established by analysis, applying accepted principles of soil mechanics. Piles or pile groups shall be assumed to transfer their loads to the underlying materials by spreading the load uniformly at an angle of 60º with the horizontal, starting at a polygon circumscribing the piles at the top of the satisfactory bearing material in which they are embedded; but the area considered as supporting the load shall not extend beyond the intersection of the 60º planes of adjacent piles or pile groups.

1817.9 Bent piles: The load bearing capacity of piles discovered to have a sharp or sweeping bend shall be determined by an approved method of analysis or by load testing a representative pile.

1817.10 Overloads on piles: The maximum compressive load on any pile due to mislocation shall not exceed 110% of the allowable design load.

1817.7.1 Required load test: A single pile or a pile group shall be load tested to not less than 200% of the design load for transient loads (i.e.: earthquake and wind) and 250% for sustained loads.

1817.7.2 Test setup and loading procedure: The load test setup, instrumentation and loading procedure shall be in accordance with ASTM D3689.

780 CMR 1818.0 STRUCTURAL STEEL PILES

1818.1 Materials: Structural steel piles and fully welded steel piles fabricated from plates shall conform to ASTM A36, A252, A283, A572 or A588 listed in *Appendix A*.

1818.2 Allowable stress: The allowable design compressive stress shall not exceed 35% of the minimum specified yield strength of the steel nor 12,600 psi. The maximum allowable design stress shall be limited to 50% of the minimum specified yield strength of the steel where higher stresses are substantiated by 780 CMR 1817.5.

1818.3 Pile cap seismic connection: All structural steel piles shall be connected to the pile cap with a connection detail designed for a minimum tensile force equal to 10% of the pile compression design *load.*

1818.4 Dimensions of H-piles: Sections of H-piles shall comply with the criteria of 780 CMR 1818.4.1 through 1818.4.4.

1818.4.1 Flanges: The flange projections shall not exceed 14 times the minimum thickness of metal in either the flange or the web, and the flange widths shall not be less than 80% of the depth of the section.

1818.4.2 Depth: The nominal depth in the direction of the web shall not be less than eight inches.

1818.4.3 Thickness: Flanges and webs shall have a minimum nominal thickness of _ inch (9.5 mm).

1818.4.4 Tip reinforcement: The tips of all steel H piles having a thickness of metal less than 5/10 inches (12.7 mm) which are driven to end bearing on rock of Classes 1 through 3 by an impact hammer shall be reinforced. The installation of all steel H piles by impact hammer to end bearing on rock of Classes 1 through 3 shall be conducted so as to terminate

driving when the pile reaches refusal on the rock surface.

780 CMR 1819.0 CONCRETE-FILLED STEEL PIPE AND TUBE PILES

1819.1 Material: Steel pipe and tube piles shall conform to ASTM A252 or A283 listed in Appendix A. Concrete shall conform to 780 CMR 1820.1.1.

1819.2 Allowable stress:

1819.2.1 Top driven piles: The allowable design compressive stress in the concrete shall not exceed 25% of the 28-day compressive strength of the concrete or 1,100 pounds per square inch whichever is smaller. The maximum allowable compressive stress in the steel shall not exceed 9,000psi.

1819.2.2 Mandrel driven piles: For piles installed with mandrels which transmit driving stresses to the bottom of the steel pipe, the allowable design compressive stress in the concrete shall not exceed 33% of the 28-day specified compressive strength. The allowable design compressive stress in the steel shall not exceed 35% of the minimum specified yield strength of the steel. The maximum allowable design stress shall be limited to 50% of the minimum specified yield strength of the steel where higher stresses are substantiated by 780 CMR 1817.

1819.3 Reinforcement: Except for steel dowels embedded five feet (1.5m) or less in the pile and as provided for in 780 CMR 1802.2 and 1802.6, reinforcement, where required, shall be assembled and tied together and shall be placed in the pile as a unit before the reinforced portion of the pile is filled with concrete.

1819.3.1 Seismic reinforcement: All pipe piles shall have over their full length a minimum area of steel, after allowance for corrosion, of 0.25 percent of the pile cross-sectional area for buildings assigned to *Seismic Performance Category C,* and a minimum area of steel of 0.50 percent for buildings assigned to *Seismic Performance Category D,* in accordance with 780 CMR 1612.2.7.

1819.3.2 Pile cap seismic connection: All concrete-filled steel pipe and tube piles shall be connected to the pile cap by providing longitudinal reinforcement at the top of the pile equal to 1 % of the pile cross-sectional area. The reinforcement shall extend into the pile for a length equal to two times the required embedment anchorage into the pile cap. The embedment in the pile cap shall equal the development length as specified in ACI 318 as listed in Appendix A. The development length to be provided in the cap is the full development length for compression without reduction in length for excess area. Field-placed dowels anchored in the concrete are acceptable.

NON-TEXT PAGE

1819.4 Minimum dimensions: Piles shall have a nominal outside diameter of not less than eight inches (203 mm) and a minimum wall thickness of 1/10 inch (2.5 mm), except that for piles driven open ended, the nominal outside diameter shall not be less than ten inches (254 mm) and the wall thickness not less than ¼ inch (6.4 mm) for diameters less than 14 inches (356 mm) and _ inch (9.5 mm) for diameters greater than 14 inches. Pipe of lesser wall thickness may be used if a suitable cast steel cutting shoe is provided.

1819.5 Placing concrete: The placement of concrete shall conform to 780 CMR 1820.1.3 and 1820.5.

780 CMR 1820.0 CAST-IN-PLACE CONCRETE PILES

1820.1 General: 780 CMR 1820.0 includes augered uncased piles, pressure injected footings (enlarged base piles), cased poured piles, and small diameter grouted piles. Unless otherwise noted, the materials, reinforcing and installation shall conform to 780 CMR 1820.1.1 through 1820.1.3.

1820.1.1 Material: All concrete shall have a 28-day specified compressive strength (f'_c) of not less than 3,000 psi (2.11 kg/mm^2). The maximum size of coarse aggregate for all concrete shall be ¾ inch (19 mm), and the concrete shall have a slump of four to seven inches (102 mm to 178 mm). If concrete is to be pumped, the mix design including slump shall be adjusted to produce a pumpable concrete.

1820.1.2 Reinforcement: Except for steel dowels embedded five feet (1.5 m) or less in the pile and as provided for in 780 CMR 1820.2 and 1820.6, reinforcement, where required, shall be assembled and tied together and shall be placed in the pile as a unit before the reinforced portion of the pile is filled with concrete.

1820.1.2.1 Seismic reinforcement: All cast-in-place concrete piles shall have minimum reinforcement of 0.25% of the pile cross-sectional area for buildings assigned to *Seismic Performance Category C*, and a minimum reinforcement of 0.50% for buildings assigned to *Seismic Performance Category D* in accordance with 780 CMR 1612.2.7. The reinforcing shall be placed in the top _ of the pile length or extend ten feet (3 m) from the top of the pile, whichever is the longer length.

For *Seismic Performance Category C* buildings, the pile reinforcing shall be a minimum of four longitudinal bars with closed ties, or equivalent spirals, having a minimum diameter of ¼ inch. The ties shall be provided at a maximum spacing of 16 times the longitudinal reinforcing bar diameter. The maximum tie spacing in the top two feet (610 mm) of the pile length shall be four inches (102 mm). Tie detailing shall be in accordance with 780 CMR 1903.4

For *Seismic Performance Category D* buildings, the pile reinforcing shall be minimum of four longitudinal bars with closed ties, or equivalent spirals, having a minimum diameter of _ inch, for piles with a diameter of 20 inches (205 mm) or less; and a minimum tie diameter of ½ inch, for piles with a diameter more than 20 inches (508 mm). The ties shall be provided at a minimum spacing of eight times the longitudinal reinforcing bar diameter. The maximum tie spacing in the top four feet (1.2 m) of the pile length shall be three inches (76 mm)

Exception: Pile ties or spirals are not required where permanent metal casing (steel pipe, steel tube or spiral-welded steel shell) is used, provided the casing has minimum thickness as follows: for *Seismic Performance Category C* buildings, 0.058 inch (1.5 mm), and for *Seismic Performance Category D* buildings, 0.070 inch (1.8mm). The steel casing must be adequately protected from corrosion due to soil, changing water levels or other subgrade conditions indicated by the site soil investigation.

1820.1.2.2 Pile cap seismic connection: All cast-in-place concrete piles shall be connected to the pile cap by extending the pile reinforcing into the pile cap for a distance equal to the development length as specified in ACI 318 listed in Appendix A. The development length to be provided in the cap is the full development length for compression without reduction in length for excess area. Field-placed dowels anchored at least twice the required cap development length are acceptable.

1820.1.3 Installation: For all cased piles, the inside of the pipe or casing shall be thoroughly cleaned to the bottom and visually inspected prior to filling with concrete. The piles shall be poured in such a manner as to exclude all foreign matter and to assure a well-formed unit of full cross-section. The concreting shall be subject to the following limitations.

1. The diameter shall not vary more than 20% from the specified value.
2. Concrete shall not be placed through water except where tremie methods are approved.

3. When depositing concrete from the top of the pile, the concrete flow shall be rapid and continuous, and centered at the top of the pile.

4. After filling with concrete, the top ten feet (3 m) shall be thoroughly rodded.
5. No pile shall be installed within a distance of nine feet (2.7 m) from a pile which has been filled with concrete for less than 12 hours, unless approved.

1820.2 Augered uncased piles:

1820.2.1 Definition: An augered uncased pile is defined as a structural member installed utilizing a hollow-stem auger no less than 12 inches (305 mm) in outside diameter which extends to satisfactory bearing materials to develop support by end bearing and/or friction in those materials.

1820.2.2 Pile diameter: The design pile diameter shall be taken as the outside diameter of the hollow stem auger.

1820.2.3 Allowable design stresses: Except as provided in 780 CMR 1817.5, the design stresses shall not exceed the following values:

1. For compression loads: The maximum allowable design stress on the cement grout or concrete shall be 33% of the specified 28-day unconfined compressive strength, but not exceeding 1,600 psi. The maximum allowable design stress on the steel reinforcing, including permanent steel casing, shall be 40% of the minimum specified yield strength, but not exceeding 24,000 psi.
2. For tension loads: The maximum allowable design tensile stress on the steel reinforcing shall be 60% of the minimum specified yield strength. The allowable design tensile stress on the cement grout shall be zero.

1820.2.4 Reinforcement: Reinforcement shall be as required in 780 CMR 1820.1., except reinforcement may be placed after withdrawal of the auger where approved by the code official.

1820.2.4.1 Concrete cover: The minimum concrete cover shall be 2½ inches (64 mm) for uncased shafts and one inch (25 mm) for cased shafts.

1820.2.4.2 Corrosion protection: Corrosion protection shall be as detailed in 780 CMR 1820.6.6.

1820.2.5 Minimum spacing: The minimum center-to-center spacing between adjacent piles shall not be less than 30 inches (760 mm) or two times the pile diameter, whichever is greater. In addition, for groups of friction piles, the overall circumference of a pile group shall exceed the sum of the circumferences of all of the individual piles within the group.

1820.2.6 Installation: Augered uncased piles shall be formed by advancing a closed-end continuous-flight hollow-stem auger of uniform diameter through unsuitable material and into a satisfactory bearing material followed by removal of the tip closure and pumping cement grout or concrete through the hollow-stem while the hollow-stem auger is extracted. During advancement, the hollow-stem auger shall be rotated rapidly such that the material through which the auger is being advanced is removed by the auger flights and is not displaced laterally by the auger. During withdrawal, if the hollow stem auger is rotated, it shall be rotated in a positive (advancing) direction.

1. The grout or concrete shall be pumped under continuous pressure and in one continuous operation. Grout or concrete pump pressures shall be measured and maintained at all times sufficiently high to offset hydrostatic and lateral earth pressures. The rate of withdrawal of the auger shall be carefully controlled to exclude all foreign matter and ensure that the augered hole is completely filled with grout or concrete as the auger is withdrawn. The actual volume of grout or concrete pumped into each hole shall be equal to, or greater than , the theoretical volume of the augered hole.
2. If the grouting or concreting process of any pile is interrupted, or a loss of concreting pressure occurs, the pile shall be redrilled to its original depth plus six inches (152 mm) (unless bearing on rock) and filled from the bottom.
3. Augered uncased piles shall not be installed within six pile diameters (center-to-center) of a pile filled with grout or concrete less than 24-hours old except where approved by the code official.

1820.2.7 Records: The owner shall engage a *registered design professional* to monitor the installation of augered uncased piles in accordance with 780 CMR 1816.13. The design professional or his representative shall make an accurate record of the installation equipment used, pile dimensions, grout or concrete volumes, reinforcement, interruptions or delays in pile installation, and all other pertinent installation data.

1820.2.8 Instrumentation: The continuous-flight auger rig utilized to install augered uncased piles shall be equipped with data logging equipment that automatically

monitors and produces a real-time printout of depth, grout or concrete pressure, grout or concrete flow, and rate of auger withdrawal. The automatic monitoring equipment shall immediately indicate to the equipment operator, and record on the printed record, any instance during the withdrawal of the hollow-stem auger where the rate of auger withdrawal times the theoretical pile cross-sectional area exceeds the rate of grout or concrete placement. A printed instrumentation readout for each pile shall be provided to the

design professional's representative upon completion of each pile.

1820.3 Driven uncased pile: No provisions.

1820.4 Pressure-injected footings: (**Enlarged base piles**)

1820.4.1 Materials: Concrete shall satisfy the provisions of 780 CMR 1820.1.1. Compacted concrete shall have a zero slump. Reinforcement shall be as provided in 780 CMR 1820.1.2.

1820.4.2 Allowable design stresses: The maximum allowable design stress on shaft concrete shall be 33% of the 28-day strength, but not exceeding 1,600 psi. The maximum allowable design stress on permanent steel casing, if at least 1/10-inch (2.5 mm) thick, and on steel reinforcing shall be 40% of the minimum specified yield strength, but not exceeding 24,000 psi.

1820.4.3 Installation: The installation of pressure-injected footings shall fulfill the following requirements:

1820.4.3.1 Base:

1. The enlarged base of a pressure-injected footing shall be formed on or in bearing materials of Classes 1 to 9 inclusive. The Class 9 material (fine sand) shall have a maximum of 15% by weight finer than the No. 200 mesh sieve and shall be non-plastic, unless satisfactory load test results or other substantiating data are submitted to, and approved by, the code official.
2. The compacted concrete placement shall be in measured batches, to establish impact energy required per unit volume of concrete. A minimum of one Standard Batch Volume of concrete, as defined in Table 1820.4, shall be injected in the base, after expulsion of the concrete plug or boot used to close the tube during the driving process.

1820.4.3.2 Shaft installation:

1820.4.3.2.1 Uncased compacted-concrete shaft:

1. Concrete shall be placed at zero slump, in small batches, and shall be compacted in place in a controlled manner as the drive-tube is withdrawn.
2. Pressure injected footings formed through soils of Classes 10 and 11, located less than nine feet or within the heave range from an uncased shaft, shall be pre-drilled through such soil.
3. An uncased compacted-concrete shaft shall not be formed through very soft to soft soils of Classes 10 and 11. The code official may waive this requirement based upon satisfactory evidence prepared by a *registered design professional* that the soil has sufficient strength for proper shaft construction.
4. A suitable method shall be employed by the contractor and the design professional to verify and record that the entire length of the shaft is completely filled with concrete. Such means shall include the ability to determine the incremental volume of concrete installed in relation to the calculated shaft volume.

1820.4.3.2.2Uncased high-slump concrete shaft:

1. Concrete shall be placed at not less than eight-inch slump, except that slump as low as four inches may be allowed if adequate vibration is applied to the drive-tube during the entire withdrawal process. During withdrawal, the level of concrete within the tube shall have a positive differential head over external soil and water pressures at all times.
2. The shaft shall be provided with full-length reinforcing steel anchored in the enlarged base. At a minimum, provide a cage with four, full length, number five reinforcing bars evenly spaced near the shaft perimeter.
3. Pressure injected footings located less than nine feet (2.7 m) from a completed uncased high-slump shaft shall not be installed until at least 12 hours after shaft pour.
4. A suitable method shall be employed by the contractor and the design professional to verify and record that the entire length of the shaft is completely filled with concrete. Such means shall include the ability to determine the incremental volume of concrete installed in relation to the calculated shaft volume.

1820.4.3.2.3 Cased shaft:

1. The permanent metal casing shall be fastened to the enlarged base in such a manner that the two will not separate.
2. Concrete shall be placed in the same manner as for cased poured concrete

piles. The requirements of 780 CMR 1820.1.3 shall apply.

1820.4.4 Loadbearing capacity:

1. Pile loadbearing capacity shall be verified by load tests as required in 780 CMR 1817.4.
2. For loads up to 120 tons, the allowable load may be computed by the following formula:

B =average number of blows required to inject one cubic foot of concrete, during injection of the last batch;
E =Energy per blow in foot-pounds;
C =constant; and
V =total volume of base concrete in cubic feet.

The values of R, E, and C shall conform to Table 1820.4 unless other values are determined by load test, in which case the latter values shall control. Use of Table 1820.4 is limited by the provisions of 780 CMR 1817.4.

The value of V shall include an allowance of one Standard Batch Volume of concrete, if concrete is used in the tube during the driving process, plus the additional volume of concrete injected during formation of the base.

3. During injection of the last batch of concrete in the base, the height of concrete within the drive tube shall not be more than _ of the drive-tube inside diameter.

TABLE 1820.4

R (tons)	Energy, E (foot-pounds)	C	Standard Batch Volume (cubic feet)
over 100	140,000	18	5
51 to 100	100,000	18	5
25 to 50	60,000	30	2

1820.4.5 Loading: The load on pressure-injected footings shall be limited by the provisions of 780 CMR 1817.8 except that the circumscribing polygon shall start at the junction of the shaft and the enlarged base, and the bearing area shall be taken at planes six feet or more below the junction, or at the top of weaker material, whichever is higher.

1820.4.6 Spacing: The center-to-center spacing of pressure-injected footings with uncased shafts shall be not less than 2½ times the outside diameter of the drive tube and not less than 3½ feet. The center-to-center spacing of pressure-injected footings with cased shafts shall be not less than three times the shaft diameter.

– $R = \frac{B \times E}{C} V$ Where:

R = allowable load in pounds;

1820.5 Cased poured concrete piles: Steel-cased piles shall comply with the requirements of 780 CMR 1820.5.1 through 1820.5.4.

1820.5.1 Materials: Concrete shall satisfy the provisions of 780 CMR 1820.1.1. Pile shells or casings shall be of steel and shall be sufficiently strong to resist collapse and sufficiently water tight to exclude any foreign materials during the placing of concrete. The shape of the pile may be cylindrical, or conical, or a combination thereof, or it may be a succession of cylinders of equal length, with the change in diameter of adjoining cylinders not exceeding one inch.

1820.5.2 Allowable design stresses: The load on cased poured concrete piles shall be as provided in 780 CMR 1817.0 and shall not exceed the load computed on the basis of 33% of the 28-day strength of the concrete, nor 1,600 psi when applied to the cross-sectional area computed on the following basis:

1. For metal-cased piles driven to and into materials of Classes 1 to 4 inclusive, using the diameter measured one foot (0.3 m) above the point, except that when the rock is immediately overlain by a bearing stratum consisting of one or a combination of bearing materials of Classes 5, 6, and 7, using the diameter at the surface of the bearing stratum.
2. For metal-cased piles, driven through compressible materials including Classes 10 and 11 and into a bearing stratum consisting of one or a combination of bearing materials of Classes 5-9 inclusive, using the diameter at the surface of the bearing stratum.

1820.5.3 Installation: Piles shall have steel shells or casings which are mandrel-driven their full length in contact with the surrounding soil, left permanently in place and filled with concrete. The requirements of 780 CMR 1820.1.3 shall apply.

1820.6 Small diameter grouted piles:

1820.6.1 General: 780 CMR 1820.6 covers grouted cast-in-place piles which are less than 12 inches (305 mm) in diameter and in which all

or a portion of the pile is cast directly against the soil without permanent casing.

1820.6.2 Materials: Concrete or sand-cement grout shall satisfy the provisions of 780 CMR 1820.1.1.

1820.6.3 Allowable load: The load on small diameter grouted piles shall not exceed the allowable load computed on the basis of the allowable stresses given in 780 CMR 1820.2.3 and the requirements of 780 CMR 1820.6.3.1 and 1820.6.3.2.

2. For a pile or a portion of a pile grouted in an open drill hole without temporary or permanent casing or grouted within materials of Classes 1 through 5, the pile shall be designed to carry the entire design compression load on the reinforcing steel. If a steel pipe section is used for reinforcing, any portion of the cement grout enclosed within the pipe may also be included at the allowable stress for the grout.

1820.6.3.2 Load test: For all design loads, the allowable load shall be determined by load tests in accordance with 780 CMR 1817.4. Load tests may be waived by the code official based on substantiating data and analyses prepared by a *registered design professional*.

1820.6.3.3 Alternative load test procedure for friction piles: For piles designed as friction piles, the friction capacity in compression may be verified by load testing in tension. The tension load test shall be performed in accordance with 780 CMR 1817.7, with the following exceptions:

1. The test pile must be cased or left ungrouted down to the top of the bearing stratum in a manner which will ensure that no friction resistance is developed above the bearing stratum.
2. The maximum design load shall be taken as 50% of the applied test load which results in a movement under load of ½ inch (13 mm) at the pile tip. The movement at the pile tip shall be a.) measured directly by a tell-tale or b.) computed by deducting the theoretical elastic elongation of the pile from the displacement measured at the top of the pile.

1820.6.4 Installation: The pile may be formed in a hole advanced by rotary or rotary percussive drilling methods (with or without temporary casing), by a hollow-stem auger, or by driving a temporary casing. The pile shall be grouted with a fluid cement grout. The grout shall be pumped through a tremie pipe extending to the bottom of the pile until grout of suitable quality returns at the top of the pile.

The following requirements apply to specific installation methods:

1. Piles grouted with temporary casing: For piles grouted inside a temporary casing, the reinforcing steel shall be inserted prior to withdrawal of the casing. The casing shall be withdrawn in a controlled manner with the grout level maintained at the top of the pile, to ensure that the grout completely fills the drill hole. During withdrawal of the casing, the grout level inside the casing shall be monitored to check that the flow of grout inside the casing is not obstructed.
2. Piles grouted without temporary casing: For a pile or portion of a pile grouted in an open drill hole in soil without temporary casing, the minimum design diameter of the drill hole shall be verified by a suitable device immediately prior to grouting. The reinforcing steel shall be inserted prior to grouting.
3. Piles grouted with hollow-stem augers: For piles installed with a hollow-stem auger, the grout shall be pumped under continuous pressure, and the rate of withdrawal of the auger shall be carefully controlled to ensure that the hole is completely filled with grout as the auger is withdrawn. The actual volume of grout pumped for each one foot (0.3 m) of withdrawal of the auger shall be recorded and must be equal to or greater than the theoretical volume. The reinforcing steel shall be inserted prior to withdrawal of the auger.
4. For piles designed for end bearing, a suitable means shall be employed to verify that the bearing surface is properly cleaned prior to grouting.
5. Subsequent piles shall not be drilled or driven near piles that have been grouted until the grout has had sufficient time to harden.

1820.6.3.1 Minimum reinforcing: The steel reinforcing shall be designed to carry the following minimum percentage of the design compression load:

1. For a pile or a portion of a pile grouted inside a temporary casing, grouted inside a hole drilled into rock, or grouted with a hollow-stem auger, the reinforcing steel shall be designed to carry not less than 40% of the design compression load.

1820.6.5 Pile diameter: The design pile diameter shall be taken as:

1. The outside diameter of the temporary casing; or
2. The diameter of a full circumferential drill bit attached to the bottom of the temporary casing; or
3. The outside diameter of the hollow-stem auger; or
4. The borehole diameter verified by suitable measurements made immediately prior to grouting.

1820.6.6 Corrosion protection:

1. Minimum grout cover: Where steel reinforcing is not enclosed inside a permanent casing, centralizers shall be provided on the reinforcing to ensure a minimum grout cover of one inch (25 mm) in soil and ½ inch (13 mm) in rock. Grout cover requirements may be reduced when the reinforcing steel is provided with a suitable protective coating.
2. Permanent steel casing that is used as structural reinforcing shall be protected in accordance with the provisions of 780 CMR 1816.4.2.
3. For piles subjected to sustained tension loading in corrosive environments, the reinforcing steel shall be protected by a suitable protective coating or encapsulation method.

1820.6.7 Records: The owner shall engage a *registered design professional* to observe the installation of the piles in accordance with 780 CMR 1816.13. The design professional or his representative shall make an accurate record of the installation equipment used, pile dimensions, grouting volumes and procedures used and all other pertinent installation data.

780 CMR 1821.0 PRECAST CONCRETE PILES

1821.1 Design and manufacture: All piles shall be designed and manufactured in accordance with accepted engineering practice to resist all stresses induced by handling, driving and service loads. The minimum lateral dimension shall be ten inches (254 mm). All corners of square piles shall be chamfered. Longitudinal steel shall be arranged in a symmetrical pattern and shall be laterally tied with steel ties or wire spiral spaced not more than three inches (76 mm) apart, center to center, for a distance of two feet (610 mm) from the ends of the pile; and not more than six inches (152 mm) elsewhere except that at the ends of each pile, the first five ties or spirals shall be spaced one inch (25 mm) center to center. When driven to or into bearing materials of Classes 1 to 6 inclusive, or through materials containing boulders, piles shall have metal tips of approved design.

1821.1.1 Installation: All piles shall be handled and driven so as not to cause injury or overstressing which affects durability or strength.

1821.2 Reinforced piles: Reinforced precast concrete piles shall conform to 780 CMR 1821.2.1 through 1821.2.5.

1821.2.1 Design: The minimum amount of longitudinal reinforcement shall be 2% of the concrete section and shall consist of at least four bars.

1821.2.2 Material: All concrete shall have a 28-day specified compressive strength (f'_c) of not less than 4,000 psi (2.81 kg/mm^2).

1821.2.3 Allowable stress: The allowable compressive stress in the concrete shall not exceed 33% of the 28-day specified compressive strength (f'_c) nor 1,600 psi applied to the gross cross-sectional area of the pile.

1821.2.4 Concrete cover: All pile reinforcement shall have a concrete cover of not less than two inches (51 mm), except that piles exposed to sea water shall have a minimum protective concrete cover of three inches (76 mm).

1821.2.5 Installation: A precast concrete pile shall not be driven before the concrete has attained a compressive strength of at least 3,000 psi (2.11 kg/mm^2), but not less than such strength sufficient to withstand handling and driving forces.

1821.2.6 Pile cap seismic connection: Precast concrete piles shall be connected to the pile cap in accordance with the requirements of 780 CMR 1820.1.2.2.

1821.3 Prestressed piles: Prestressed concrete piles shall conform to the requirements of 780 CMR 1821.3.1 through 1821.3.6.

1821.3.1 Design: The effective prestress in the pile shall not be less than 700 psi (0.49 kg/mm^2).

1821.3.2 Material: Prestressing steel shall conform to ASTM A416 listed in ***Appendix A***. All concrete shall have a 28-day specified compressive strength (f'_c) of not less than 5,000 psi (3.52 kg/mm^2).

1821.3.3 Allowable stress: The maximum allowable design compressive stress (f_c) in concrete shall be determined as follows:

$$f_c = 0.33\, f'_c - 0.27\, f_{pc}$$

where f'_c is the 28-day compressive strength and f_{pc} is the effective prestress on the gross area of the pile section; however, 0.33 f'_c shall not exceed 1,600 psi.

1821.3.4 Installation: A prestressed pile shall not be driven before the concrete has attained a compressive strength of at least 4,000 psi (2.81 kg/mm2), but not less than such strength sufficient to withstand handling and driving forces.

1821.3.5 Pile cap seismic connection: Prestressed concrete piles shall be connected to the pile cap in accordance with the requirements of 780 CMR 1820.1.2.2 or by extension of the pile reinforcing strand into the pile cap. The embedment of reinforcing into the pile cap shall develop the strength of the reinforcing strand. Prestressed pile cap connections in buildings assigned to *Seismic Performance Category D*, in accordance with 780 CMR 1612.2.7, shall not be by development of exposed strand.

1821.3.6 Spiral seismic reinforcing: The upper two feet of the pile immediately below the pile cap shall have No. 3 ties minimum at not over four-inch spacing, or equivalent spirals. The spiral reinforcement in prestressed piles for buildings assigned to *Seismic Performance Category D*, in accordance with 780 CMR 1612.2.7, shall not be less than 0.6% for the full length of the pile where subjected to vertical *loads* only or where the design bending moment does not exceed 20% of the unfactored ultimate moment capacity at balanced strain conditions computed in accordance with ACI 318 listed in ***Appendix A***.

780 CMR 1822.0 TIMBER PILES

1822.1 Materials: Round timber piles shall conform to ASTM D25 listed in ***Appendix A***. Round timber piling shall be new longleaf, shortleaf, loblolly or slash species of Southern pine, oak, Douglas fir or other woods of similar strength and physical characteristics.

1822.2 Preservative treatment: Timber piles used to support permanent structures shall be pressure treated in accordance with AWPA C3 listed in ***Appendix A*** for round timber piles. Preservative-treated timber piles shall be subject to a quality control program administered by an approved agency. Pile cutoffs shall be treated in accordance with AWPA M4 listed in ***Appendix A***.

1822.3 Allowable load:

1822.3.1 Allowable stress: The allowable stress in the timber shall not exceed 1,000 psi in compression at the critical cross-sectional area taken at the top of the bearing stratum. Piles designed for end bearing on materials of Classes 1 through 5 shall be designed for a maximum stress of 500 psi in compression on the pile cross-sectional area at the tip.

1822.3.2 Maximum Load: The load on timber piles shall not exceed the allowable load specified in 780 CMR 1817.0 nor 35 tons, whichever is smaller.

1822.3.3 Minimum dimensions: Timber piles shall be sized to conform to the minimum tip sizes as specified in ASTM D25 but no less than six inches (152 mm) in diameter at the tip.

1822.4 Precautions during driving:

1822.4.1 Hammer energy: Pile hammer energy shall be selected to prevent damage to the pile, but in no case shall the maximum hammer energy, as rated by the manufacturer, exceed 18,000 ft. lbs. For end bearing piles, on materials of Class 1 through 5, the maximum hammer energy shall be reduced.

1822.4.2 Driving resistance: Driving shall be stopped immediately when abrupt high resistance to penetration is encountered. Any sudden decrease in driving resistance of an end-supported timber pile shall be investigated with regard to the possibility of damage. If the sudden decrease in driving resistance cannot be correlated to loadbearing data, the pile shall be removed for inspection or rejected.

780 CMR 1823.0 COMPOSITE PILES

1823.1 Design: Composite piles consisting of two or more approved pile types shall be designed to meet the conditions of installation.

1823.2 Limitation of load: The maximum allowable load shall be limited by the capacity of the weakest section incorporated in the pile.

1823.3 Splices: Splices between concrete and steel or wood sections shall be designed to prevent separation both before and after the concrete portion has set, and to insure the alignment and transmission of the total pile load. Splices shall be designed to resist uplift caused by upheaval during driving of adjacent piles, and shall develop the full compressive strength and not less than

50% of the tension and bending strength of the weaker section.

780 CMR 1824.0 CONCRETE-FILLED PIPE WITH STEEL CORE CAISSONS

1824.1 Construction: These units shall consist of a shaft section of concrete-filled pipe extended to and firmly seated in bedrock of Classes 1 or 2 with an uncased socket drilled into the bedrock which is filled with cement grout. A steel core shall be centered in the shaft and shall extend through the cement grout to the bottom of the socket.

1824.2 Rock socket: A socket, approximately the inside diameter of the pipe, shall be made in bedrock of Classes 1 or 2 to a depth that will assure load transfer when computed for bearing on the bottom surface of the socket in accordance with 780 CMR 1803.0, 1807.0 and 1817.0 acting together with a bond stress on the perimeter surface of the socket. The socket design stress shall be determined by a *registered design professsional* based upon foundation investigation study in accordance with 780 CMR 1816, but in no case will the design bond stress on the perimeter of the socket exceed 200 psi. Load tests, in accordance with 780 CMR 1817.4, may be required by the code official if foundation investigation data are judged insufficient to verify the selected bond stress. The minimum socket depth shall be at least equal to the diameter of the pipe. Before placement of concrete, the socket and pipe shall be thoroughly cleaned and the rock **1824.7 Installation**: The rock socket and pile shall be thoroughly cleaned of all foreign materials before filling with cement grout and concrete. Steel cores shall be bedded in cement grout at the base of the rock socket.

1824.8 Spacing: The minimum center-to-center spacing shall be not less than 2½ times the outside diameter of the steel shell.

780 CMR 1825.0 RETAINING WALLS

1825.1 General: Walls built to retain or support the lateral pressure of earth or water or other superimposed loads shall be designed and constructed of approved masonry, reinforced concrete, steel sheet piling or other approved materials within the allowable stresses specified in 780 CMR 2311.7.

1825.2 Design: Retaining walls shall be designed to resist the pressure of the retained material, including both *dead* and *live load* surcharges to which such walls are subjected, and to insure inspected by a *registered design professional* or his qualified representative.

1824.3 Seismic design: All caisson piles shall meet the seismic design requirements of 780 CMR 1819.3.

1824.4 Material: Pipe and steel cores shall conform to the material requirements in 780 CMR 1818.0. Pipe shall have a minimum diameter of 18inches (457 mm) and a minimum wall thickness of _ inch (9.5 mm) and shall be fitted with a suitable steel driving shoe welded to the bottom of the pipe. All concrete shall have a 28-day specified compressive strength (f'_c) of not less than 4,000 psi (2.81 kg/mm^2). The concrete mix shall be designed and proportioned so as to produce a cohesive workable mix with a slump of four inches (102 mm) to six inches (152 mm).

1824.5 Structural core: The gross cross-sectional area of the structural steel core shall not exceed 25% of the gross area of the caisson. The minimum clearance between the structural core and the pipe shall be two inches (51 mm). If cores are to be spliced, the ends shall be milled or ground to provide full contact and shall be full-depth welded.

1824.6 Allowable stress: The allowable design compressive stresses shall not exceed the following: concrete, 0.33 f'_c; steel pipe, 0.35 f_y; and structural steel core, 0.50 f_y.

stability against overturning, sliding, excessive foundation pressure and water uplift. Retaining walls shall be designed to resist seismic loads in accordance with 780 CMR 1612.4.9.

1825.3 Hydrostatic pressure: Unless drainage is provided, the hydrostatic head of the water pressure shall be assumed to be equal to the height of the wall.

1825.4 Coping: All masonry retaining walls, other than reinforced concrete walls, shall be protected with an approved coping.

1825.5 Guards: Where retaining walls with differences in grade level on either side of the wall in excess of four feet (1.2 m) are located closer than two feet (0.6 m) to a walk, path, parking lot or driveway on the high side, such retaining walls shall be provided with guards that are constructed in accordance with 780 CMR 1021.0 or other approved protective measures.